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Technical Report

EXPERIMENTS IN MONTHLY MEAN SIMULATION OF THE ATMOSPHERE WITH A COARSE-MESH GENERAL CIRCULATION MODEL

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Corrections for Technical Report:

"Experiments in Monthly Mean Simulation of the Atmosphere with a Coarse-Mesh General Circulation Model" by Robert J. Lutz, NASA, Goddard Space Flight Center, Grant NGR 33-016-086 (Supplement No.5).

p. 10. Energy units are $10^5 Jm^{-2} \sigma^{-1}$ (per unit sigma)

p. 41, 2nd paragraph, should read:

"The S1 scores shown in Table 4 indicate that the Hansen model, like the GISS model, exhibits no skill in simulating the sea-level pressure field. (Over the northern hemisphere, the five-month average S1 score for sea-level pressure is 93, a "worthless" forecast.) At the 850 mb level, the S1 scores for the simulations of the temperature patterns are much better, especially over the United States. However, over the northern hemisphere only marginal skill in indicated for the 850 mb simulation. For the 500 mb height field, the S1 scores are satisfactorily low over the United States. But, over the northern hemisphere they are disappointingly high, with a five-month average value of 64, compared with the four-month GISS model average of 46. This suggests only marginal skill for the Hansen model at the 500 mb level compared with the more satisfactory performance of the GISS model." (The underlined words were omitted from the distributed report.)

p. 44 (corrected reference)

Lacis, A. A. and J.E. Hansen, 1974: A parameterization for the absorption of solar radiation in the earth's atmosphere. J. Atmos. Sci., 31, 118-133.

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Abstract

The Hansen atmospheric model has been used to compute five monthly forecasts (October 1976 through February 1977), each being initialized on the first day of the month. Each monthly forecast is time-averaged over the month and compared with the averaged monthly observed values. The comparison is based on an energetics analysis, meridional and vertical profiles, error statistics, and prognostic and observed mean maps.

The monthly mean model simulations suffer from several defects. Tropospheric temperatures are too cold, especially in the Arctic. The thermal pattern over North America during this anomalous winter is not reproduced adequately. Amplitudes of tropospheric wave patterns are too flat in the simulations compared with the real atmosphere. There is, in general, no skill in the simulation of the monthly mean sea-level pressure field, and only marginal skill is indicated for the 850 mb temperatures and 500 mb heights. The coarse-mesh model appears to generate a less satisfactory monthly mean simulation than the finer mesh GISS model.

Introduction

General circulation models have been employed successfully to simulate numerically various climatological features of the global atmosphere. Attempts have also been made to utilize these models for long-range weather prediction and to test hypotheses about the causes of anomalous atmospheric behavior. The present study is a continuation of this research effort, using data for the winter season of 1976-1977.

The Goddard Institute for Space Studies (GISS) General Circulation Model (GCM) is a nine-level, four degree by five degree latitude-longitude spherical coordinate (46 by 72), primitive equation numerical model. It uses Arakawa's (1972) numerical method and a variation of Phillips (1957) "sigma" vertical coordinate, with the atmosphere divided into nine layers between the surface and a top at 10 mb. It is integrated in five-minute time steps, and a global 24-hour forecast requires roughly 45 minutes of IBM 360/95 computer time. A description of the GISS model has been presented by Somerville, et al. (1974).

The GISS GCM has been used to compute several global monthly mean forecasts (Spar, et al., 1976; Spar, 1977 a; Spar, et al., 1978; and Spar and Lutz, 1978). There are various reasons why a monthly mean forecast is desirable

for analysis. It has been proposed by Namias (1953) that certain large-scale atmospheric anomalies may last longer than a month, and it is hypothesized that, through time averaging, the shorter-lived and smaller-scale components of the atmosphere will be filtered out. It is also hoped that the effects of phase error will be diminished somewhat in a monthly mean forecast. In the study of Spar, et al. (1976), January forecasts were computed for 1973, 1974, and 1975, all using the same January climatological sea-surface temperature field. The general structure and circulation of the mean troposphere was adequately simulated, but the interannual variations of the mean energetics and zonally averaged circulation were not accounted for satisfactorily. It was concluded that the GISS model was not capable of adequately reproducing the interannual variations of the monthly mean state of the atmosphere, given only different initial conditions at the beginning of each month. The model was found to lack skill in reproducing the sea-level pressure field, except for one successful simulation of the observed interannual change in the depth of the mean January Icelandic low. However, the model did exhibit consistent skill in forecasting the monthly mean 500 mb height field over the northern hemisphere in the three January forecasts.

In this study, we have utilized the "Hansen"[1] GCM, a revised version of the GISS model. Like the GISS model, it is a nine-level, spherical coordinate, primitive equation numerical model, which differs principally in the resolution and physics used. The Hansen model was developed for use in long-term climatological simulations and, therefore, uses a coarser grid than the GISS model. This is an approximately eight degree by ten degree latitude-longitude grid, which corresponds to 24 by 36 grid points. To compensate for the greater distance between grid points, the specified surface condition for each grid point represents appropriate fractions of land and ocean. The radiation scheme of the GISS model has been replaced by a generalized "K-distribution method," (Lacis and Hansen, 1974), which explicitly includes multiple scattering and implicitly integrates over wavelengths. The Hansen model also treats clouds of finite optical thickness as non-block bodies, in place of the black body assumption of the GISS model. One result of these (and other) changes is that a 24-hour forecast takes approximately eight minutes with the Hansen model, as opposed to 45 minutes with the GISS model on the IBM 360/95 computer.

[1]The new model was developed by a research group under the direction of Dr. James Hansen. A description and documentation of the "Hansen" model is in preparation, but preliminary notes on the model are available (Hansen, 1978).

The present study represents a test of the coarse-mesh Hansen model at one stage of the model's continuing development, in terms of its ability to simulate the monthly mean state of the atmosphere from given initial and surface boundary conditions.

Data

All observational data for the monthly forecast computations were compiled from National Meteorological Center (NMC) global analyses. These values are derived from the Flattery spherical harmonic global analysis scheme. Additional data tapes were supplied by the National Center for Atmospheric Research (NCAR). The NMC global sets provide the data on constant pressure surfaces on a 2.5 degree by 2.5 degree latitude-longitude grid for both hemispheres. These are interpolated horizontally to the approximately eight degree by ten degree Hansen GCM grid and vertically to the model's "sigma" coordinate levels for insertion into the model. No balancing, filtering, smoothing or other initialization procedure is applied after interpolation.

Procedure

In previous monthly forecast experiments, the monthly mean observed conditions over North America were not too different from the climatological values. It was thought that an interesting test of the model would be an anomalous set of meteorological conditions to determine if the model can generate realistic departures from climatology. The cold North American winter of 1976-1977 was chosen as such a test period.

The model was initialized using NMC data at 00 GMT on the first day of each month. Climatological SST values for each month were used as fixed surface boundary conditions. The 12-hourly outputs of the five monthly forecasts were then time-averaged to obtain five monthly mean forecasts. The model generates forecasts on "sigma" surfaces and, therefore, an interpolation routine was used to convert "sigma" level forecast information back to constant pressure surfaces after time-averaging. The NMC data, also recorded at 12-hourly intervals, was similarly averaged to obtain monthly mean observed conditions.

The evaluation of the experiment is based on several methods of analysis:

<u>Energetics</u>: The energetics of the predicted and observed atmospheres for the tropospheric region are compared.

Meridional and Vertical Profiles: Forecast and observed meridional profiles of the vertically-averaged mean zonal circulation for each month are compared, as are selected vertical profiles of mean zonal wind.

Prognostic and Observed Mean Maps: To illustrate the synoptic output of the model, computer digitized maps of forecast and observed monthly mean values are shown. The fields compared are those of sea-level pressure, 850 mb temperature and 500 mb geopotential height.

Error Statistics: The statistical analysis is based on root-mean-square (rms) errors, S1 (gradient) skill scores (Teweles and Wobus, 1954), and algebraic mean errors (bias). The statistical analysis is applied to sea-level pressures, 850 mb temperatures and 500 mb heights.

Energetics Analysis

A comparison of mean observed and forecast energies is presented in Table 1 for each of the five months. As in Spar, et al. (1976), K_M and P_M represent the mean zonal kinetic and available potential energies, while K_E and P_E are the eddy kinetic and eddy available potential energies of the mean flow (standing waves only). Northern hemispheric and global data are both shown, but only the northern hemispheric energetics will be discussed in any detail, as the southern hemisphere's observed and forecast fields are at times questionable and/or unreliable. The eddy energies presented here should not be compared with previous calculations by Spar, et al. (1976), as they do not include the energies of the transient eddies, but represent only the energies of the standing eddies in the monthly mean flow.

As shown in Table 1, K_E and P_E are consistently underestimated by the model. Part of this underestimate may be explained by the coarse resolution of the model (Tenenbaum, 1976), although there may be more basic dynamical reasons as well. On the other hand, P_M and K_M are consistently overpredicted. P_M and K_M are strongly dependent on the meridional temperature gradients, which are overestimated because of the model's generation of extremely low temperatures at high latitudes. This

Table 1: **Energetics of Mean Monthly Observations (O) and Forecasts (F)**

Units: $10^5\ Jm^{-2}$ $^{-1}$

K_M = Mean zonal kinetic energy

K_E = Eddy kinetic energy

P_M = Mean zonal available potential energy

P_E = Eddy available potential energy

a) NORTHERN HEMISPHERE

Energy	Oct. 1976 O	Oct. 1976 F	Nov. 1976 O	Nov. 1976 F	Dec. 1976 O	Dec. 1976 F	Jan. 1977 O	Jan. 1977 F	Feb. 1977 O	Feb. 1977 F
K_M	4.6	6.0	6.2	8.3	8.1	10.3	10.2	11.7	10.1	12.7
K_E	1.7	1.1	2.9	1.2	3.0	2.0	3.4	1.8	3.0	1.7
P_M	40.5	50.8	49.0	60.2	58.8	66.2	59.8	72.3	65.8	70.5
P_E	16.4	15.0	18.2	15.9	18.6	17.6	19.6	18.1	17.5	16.4

b) GLOBE

Energy	Oct. 1976 O	Oct. 1976 F	Nov. 1976 O	Nov. 1976 F	Dec. 1976 O	Dec. 1976 F	Jan. 1977 O	Jan. 1977 F	Feb. 1977 O	Feb. 1977 F
K_M	6.6	8.4	6.4	8.3	7.0	8.2	7.8	8.4	7.9	8.9
K_E	1.7	1.2	2.1	1.1	2.0	1.4	2.2	1.3	2.0	1.3
P_M	57.5	67.4	55.6	66.5	54.5	61.8	56.6	65.9	62.5	67.5
P_E	13.0	11.3	13.7	11.6	13.5	12.6	14.0	12.6	12.8	12.3

problem, which was also present in the GISS model, is apparently due to the inability of the model to transfer enough sensible heat by eddies to high latitudes (Stone, et al., 1975). In a coarse-mesh model this problem should be even more severe. Indeed, the diagnostic calculations of the Hansen model do show a marked underestimate of the eddy transfers of sensible heat. The predicted and observed seasonal trends of the energies are roughly similar, and do resemble the climatological behavior shown by Peixoto and Oort (1974). However, in some instances the model does not accurately simulate the month-to-month changes. For example, the observed K_M reaches a maximum in January while the forecast value peaks in February. K_E is forecast to reach a maximum in December, but the observed maximum occurs in January. And in the case of P_M, the observed and forecast maxima are found in February and January respectively.

Wind Analysis

In this section, an analysis of how well the model simulates the circulation of the atmosphere is presented. Meridional profiles of the vertically-averaged mean zonal wind and vertical profiles of the zonally averaged mean zonal wind are shown in Figures 1 and 2 respectively. The vertical wind profiles in Figure 2 are shown for the latitude of the observed northern hemispheric jet stream, which may or may not coincide with the forecast northern hemispheric jet stream. Solid curves in all diagrams represent the observed values and the dashed curves indicate the forecast values. Positive values in both figures denote westerlies, and negative values indicate easterly winds.

The meridional profiles shown in Figure 1 indicate a rough general similarity between the observed and forecast seasonal trends of the mean zonal winds, with stronger winds and an equatorward shift of the maxima from fall to winter in the northern hemisphere. However, the model simulation fails to reproduce the observed wind profile in several important details, such as the latitudes of the maxima in November and December, and the magnitude of the maximum in January.

In the vertical wind profiles at the latitude of the observed jet streams, shown in Figure 2, the shape

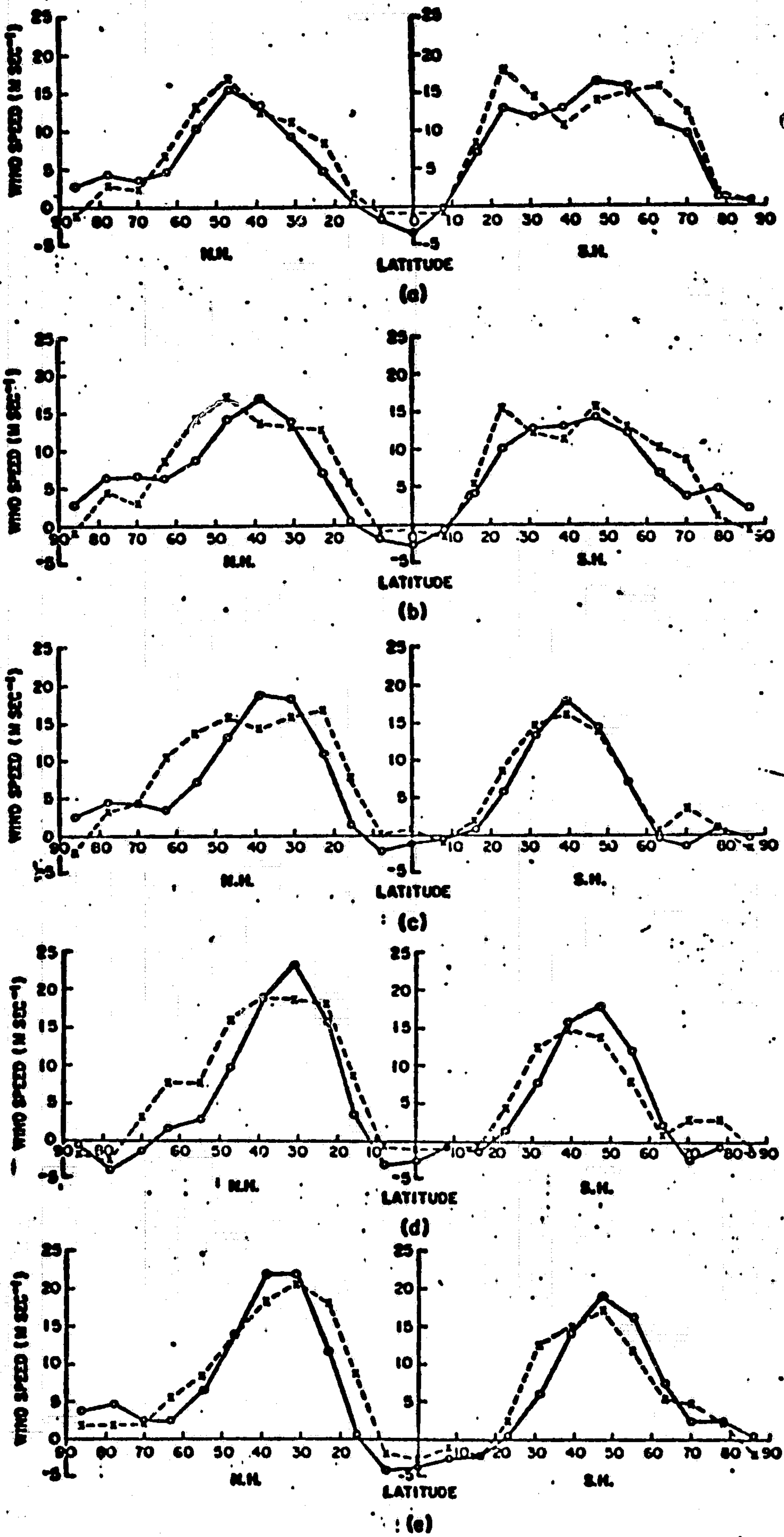


Figure 1 Meridional profiles of mean zonal wind (m s^{-1}) averaged over pressure and longitude for a)Oct.1976, b)Nov.1976, c)Dec.1976, d)Jan.1977, and e)Feb.1977. Solid curves, observed; dashed curves, forecast.

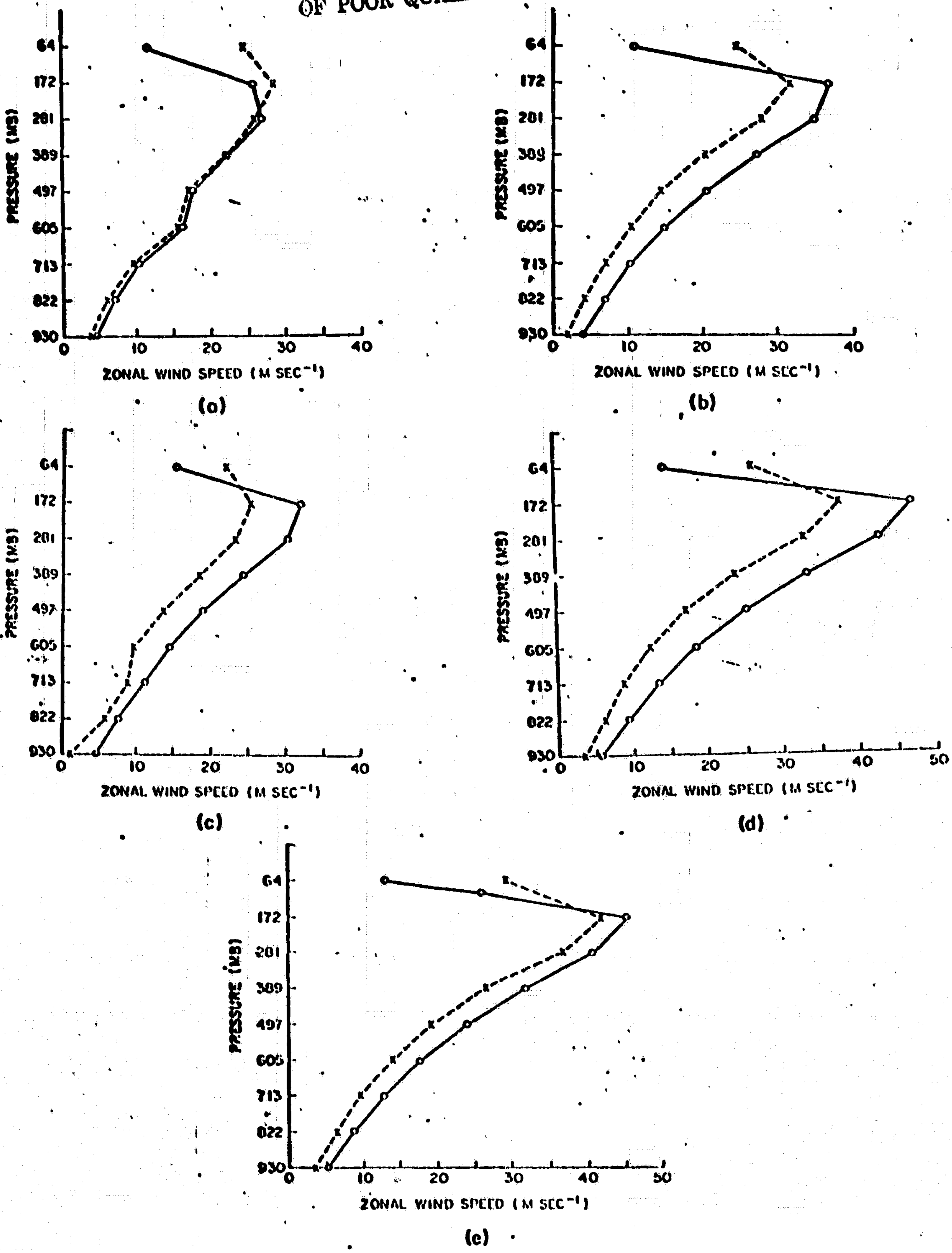


Figure 2 Vertical profiles of zonally averaged mean zonal winds at the latitude of the observed Northern Hemisphere jet stream for a)Oct.1976, b)Nov.1976, c)Dec.1976, d)Jan.1977, and e)Feb.1977. Solid curves, observed; dashed curves, forecast. (m s^{-1})

of the wind profile is well-simulated each month. However, in every month but October, the tropospheric wind speeds are underestimated in the model simulation, as is the jet stream velocity. The discrepancy is particularly large in January 1977, when the observed westerlies were unusually strong and the model predicted only normal westerlies. This result is the reverse of that reported by Spar, et al. (1976) and Spar (1977 a) for the GISS-model simulations of January 1973, 1974, and 1975. In those calculations the model overpredicted the strength of the jet-latitude westerlies. The difference may be due to the coarser resolution of the Hansen model.

Prognostic and Observed Monthly Mean Maps

The characteristics of the anomalous cold winter of 1976-1977 began to appear over North America during the latter half of September (Taubensee, 1976) in the form of a deep tropospheric trough near the east coast of North America and a strong ridge in the west. As a result of this upper air flow pattern, which persisted through January, record low temperatures developed over the eastern United States, while temperatures were abnormally warm in the west (Wagner, 1977 a; Dickson, 1977 a; Taubensee, 1977; Wagner, 1977 b). In January the wave pattern amplified still further (Wagner, 1977 b), leading to repeated advection of Arctic air southward into the eastern United States, where surface temperatures fell far below normal, notably in the Ohio Valley, producing one of the coldest months on record.

February brought about a modification and eventually a breakdown of this anomalous situation (Dickson, 1977 b). The mean ridge over the Pacific Northwest moved eastward and the wave pattern flattened. Particularly during the last week in February, the mid-tropospheric circulation over North America changed abruptly. The large-amplitude wave pattern, which had dominated the winter season, broke down and gave way to fast westerlies with fast moving storm systems traveling across the country. With

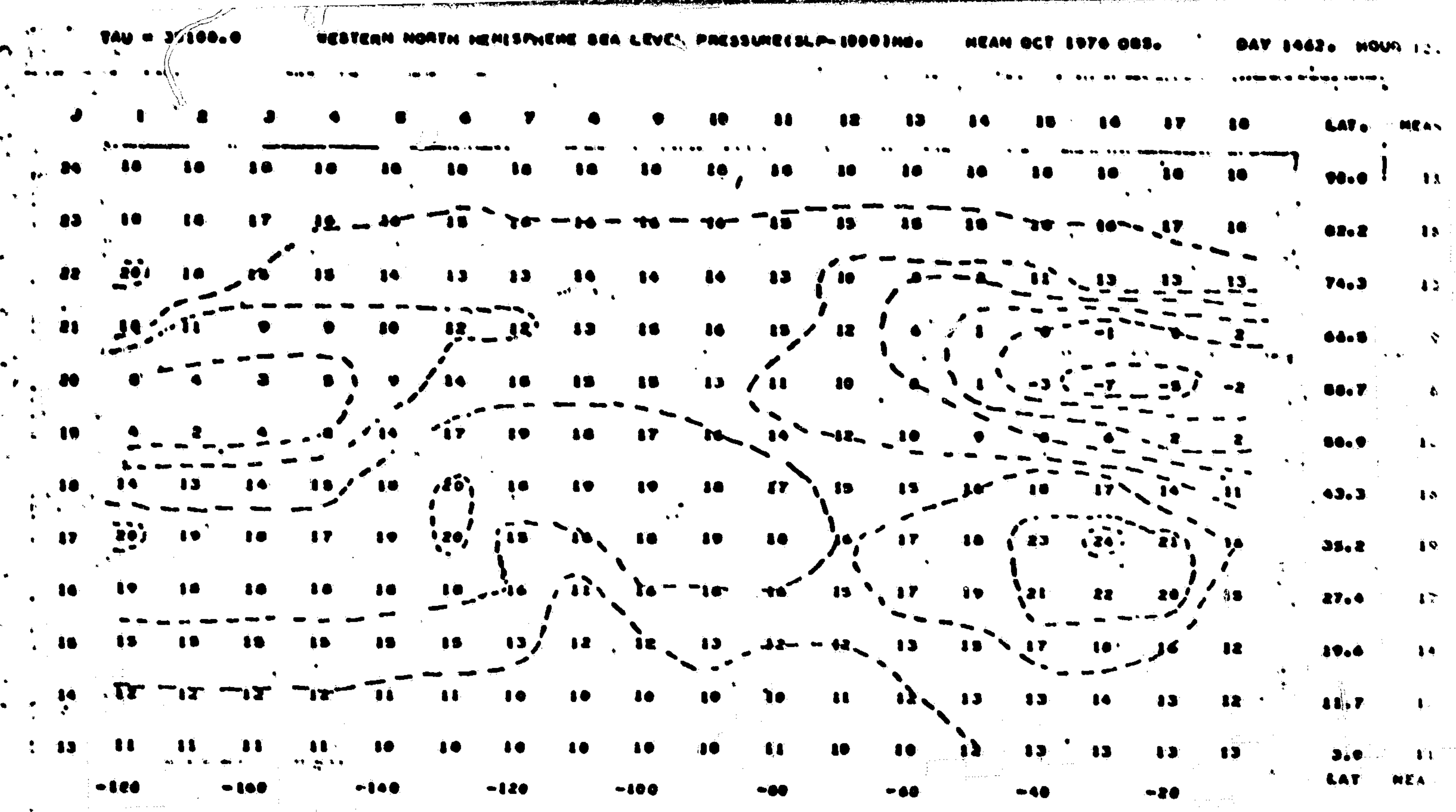
westerly flow now dominant, warm air spread quickly across the country and temperatures rose above normal in the eastern United States.

How well the model simulation reproduced the anomalous circulation and temperature fields during the winter of 1976-1977 will now be examined. To display the synoptic output of the model, digitized monthly mean maps were printed out for both forecast and observed values over the globe, as well as separately for the four quadrants of the earth. The three variables displayed are sea-level pressure, 850 mb temperature and 500 mb geopotential height, which are plotted in units of mb - 1000, degrees Celsius and decameters - 500, respectively. For the purposes of the present paper, only one quadrant is shown: the western half of the northern hemisphere. Figures 3, 4, and 5 illustrate the fields of observed (top) and predicted (bottom) sea-level pressure, 850 mb temperature, and 500 mb height, respectively, for each of the five months over this northwest quadrant.

In Figures 3, 4, and 5 North America lies in the center of the region, with the North Atlantic Ocean in the right-hand third of the map and the eastern North Pacific Ocean on the left. Longitudes are labeled at the bottom of each map, which extends from 10° W on the right to 180° W on the left, the negative numbers denoting

west longitude. The latitudes of the grid points are shown in the second column on the right of each map in degrees North. (Note that the latitude interval is approximately, but not exactly, eight degrees.) The first column on the right of each map shows the sonal mean value of the variable displayed within the quadrant.

In Figure 3, sea-level isobars have been drawn manually at an interval of 4 mb. It is apparent from an inspection of the maps in Figure 3 that the model fails to simulate adequately the monthly mean sea-level pressure fields. Although the Icelandic and Aleutian lows, as well as the sub-tropical high pressure cells over the oceans and the North American continental high, are all reflected to some degree in the model simulations, the quantitative agreement between the observed and predicted mean fields must be characterized as "poor." Most notable are the failures to simulate the abnormally deep Aleutian lows in January and February, and the strong pressure gradients in the North Atlantic in October, November, January and February, caused by the inadequate simulation of the Icelandic lows and Azores-Bermuda highs. In general, the model-generated monthly mean sea-level pressures are too high in high latitudes and too low in low latitudes.



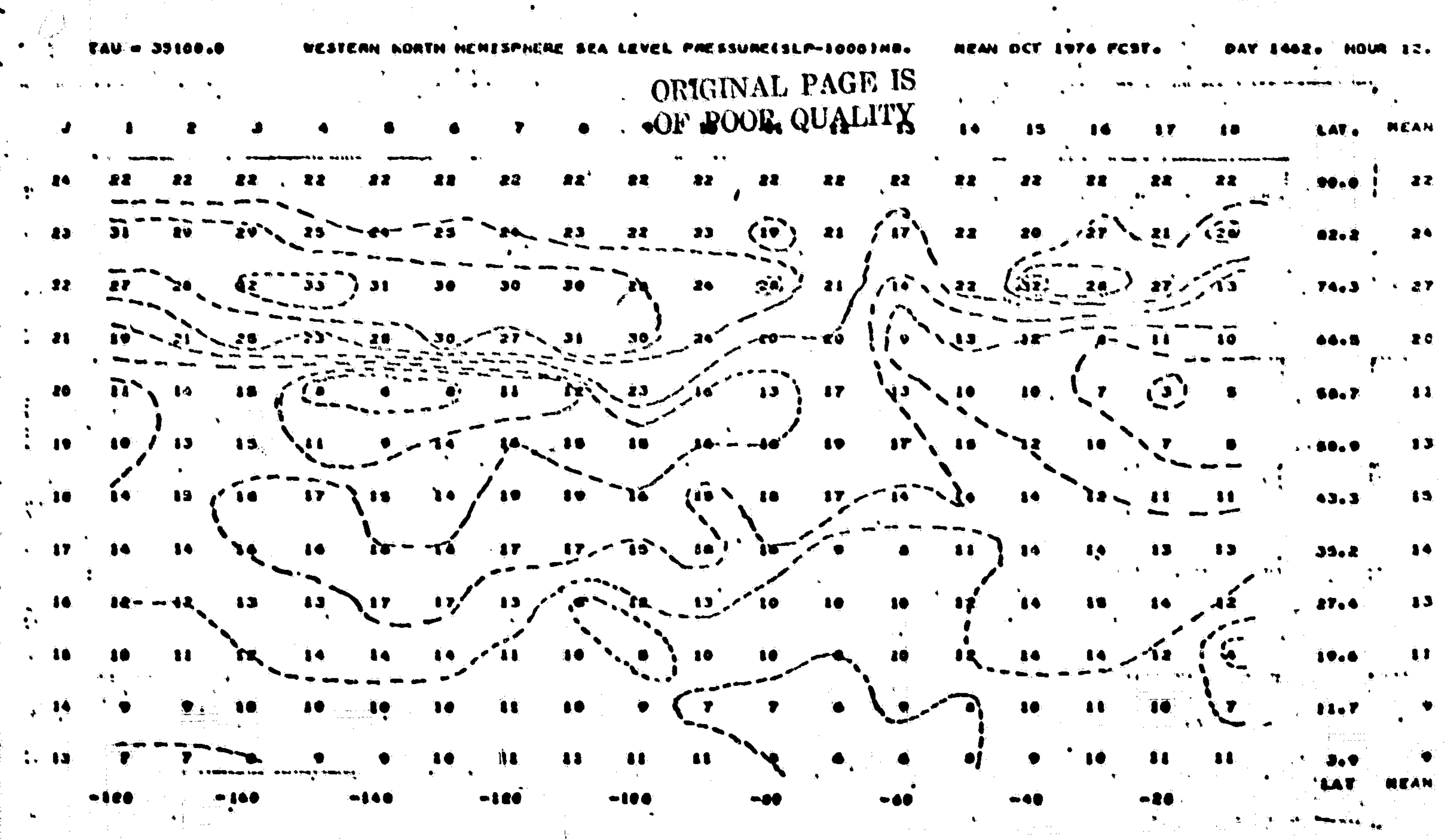
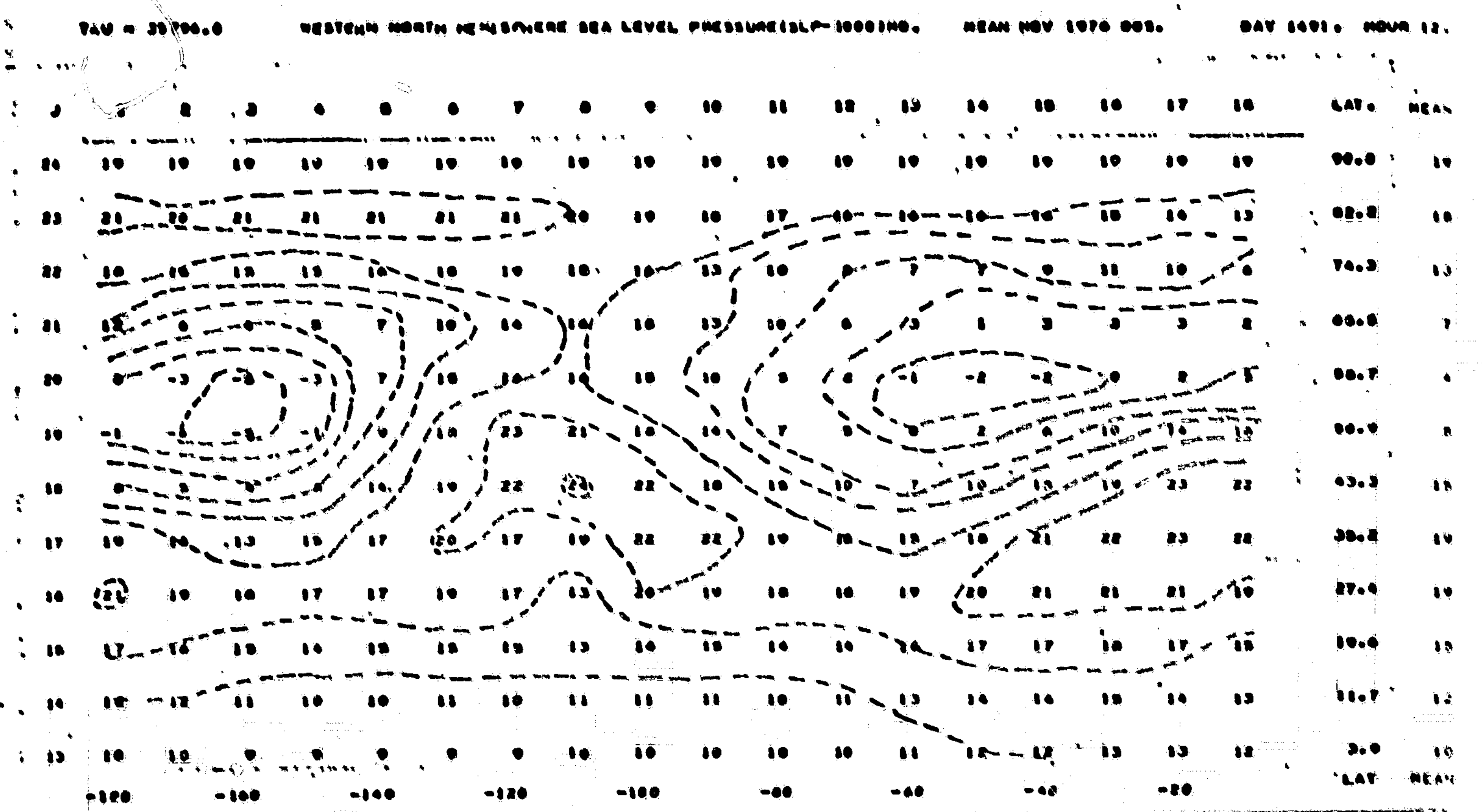


Figure 3(a) Sea-level pressure fields, observed (top) and forecast (bottom), of the northwestern hemisphere for October 1976.



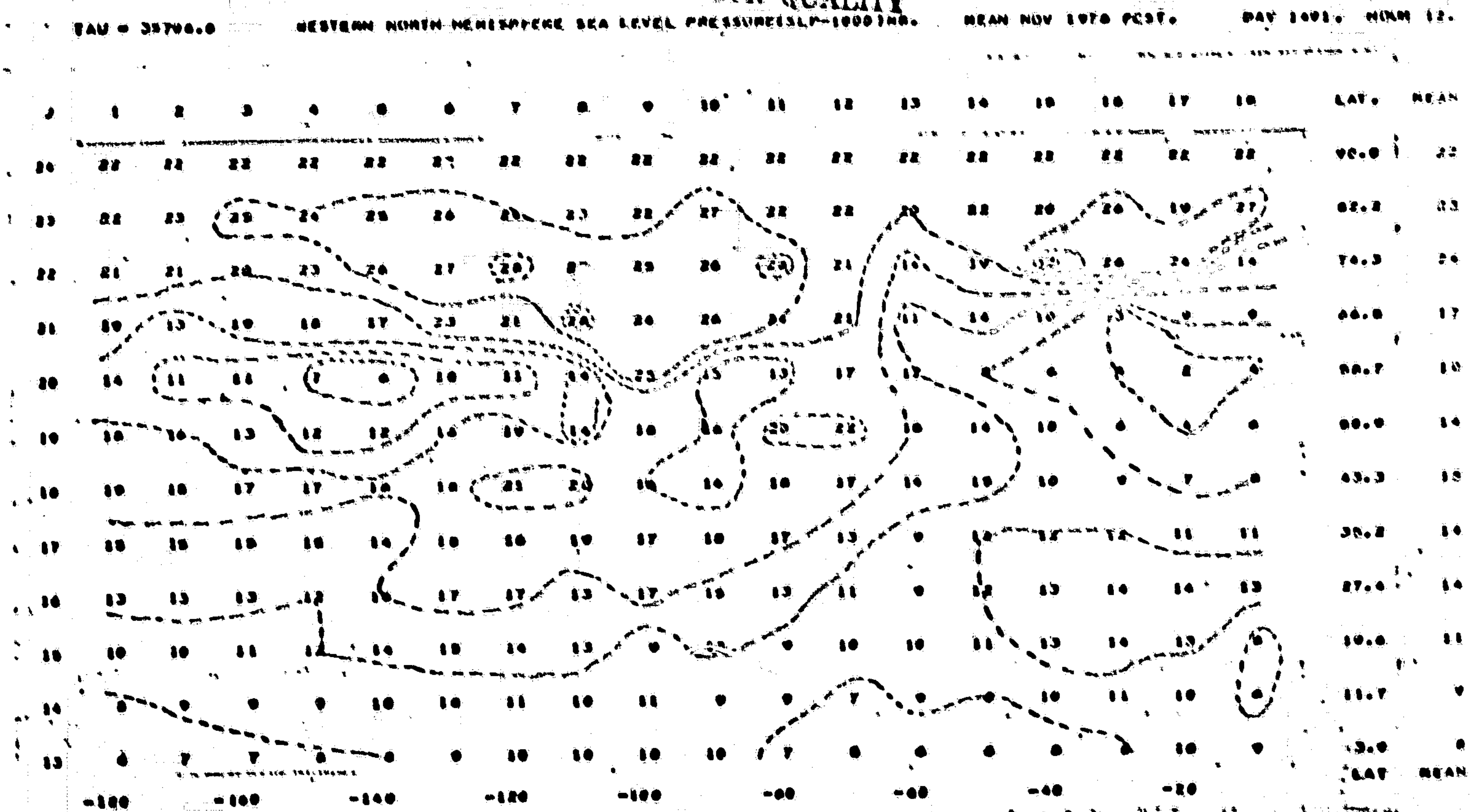
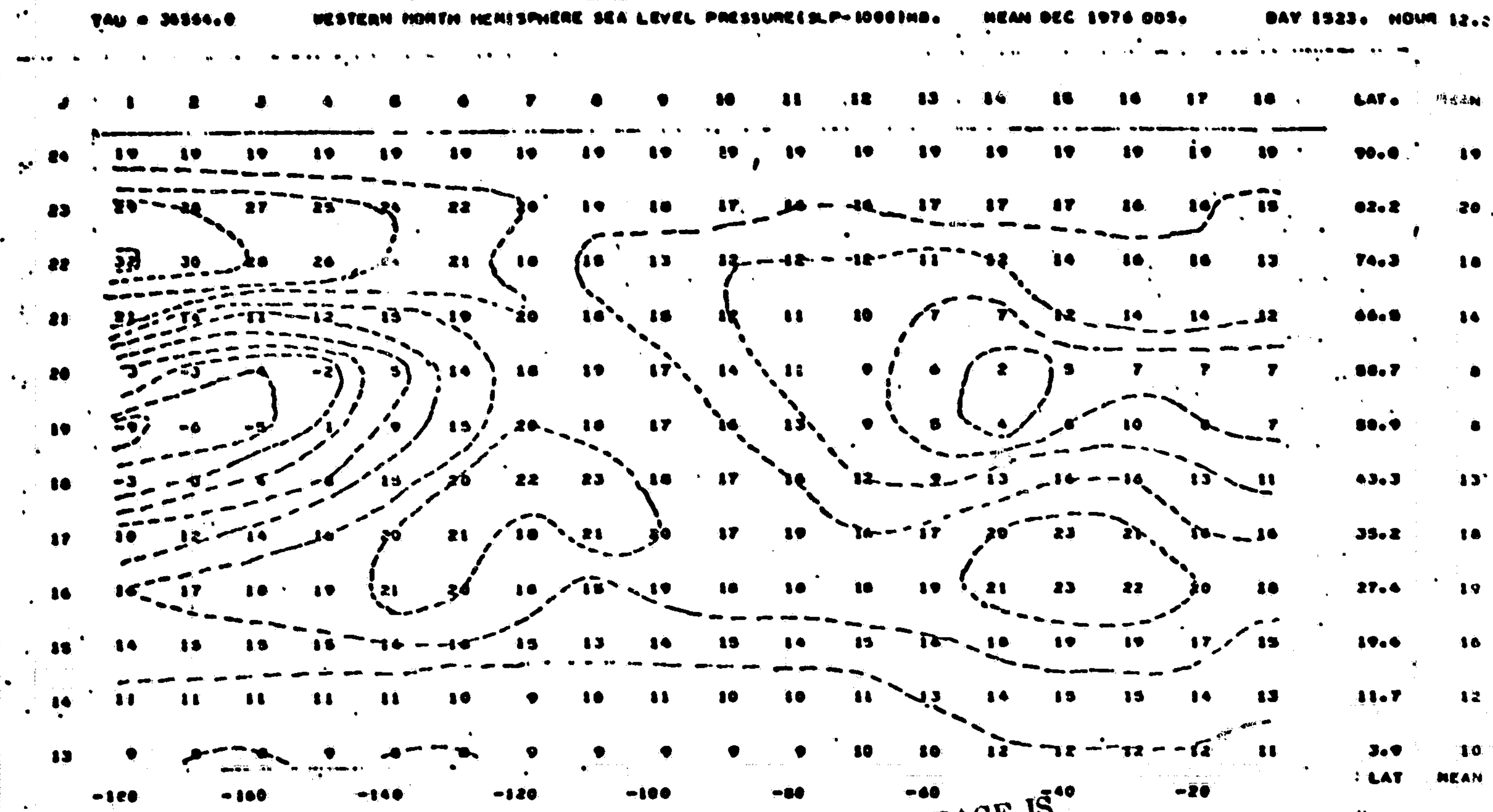


Figure 3(b) Sea-level pressure fields, observed (top) and forecast (bottom), of the northwestern hemisphere for November 1976.



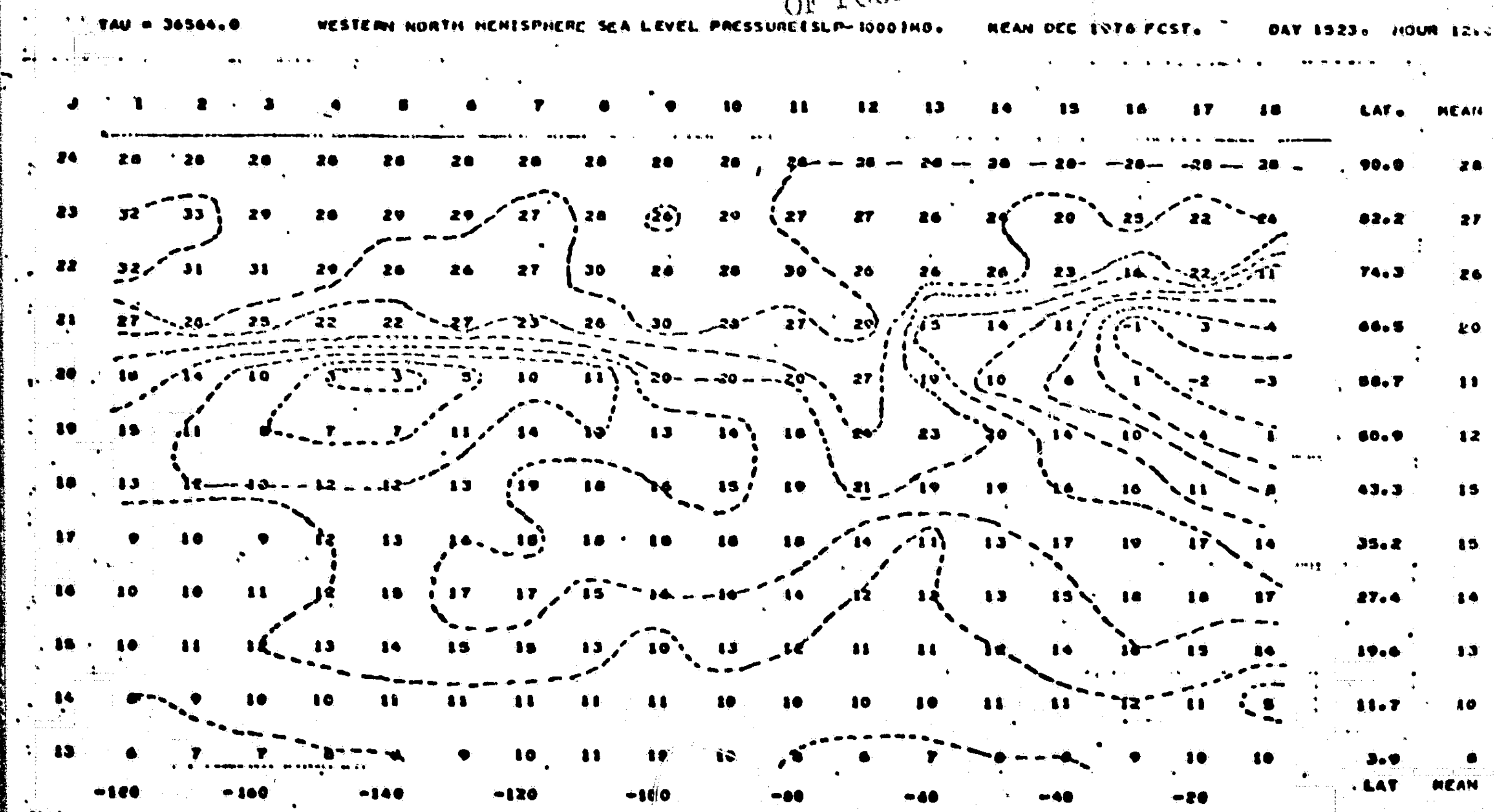


Figure 3(c) Sea-level pressure fields, observed (top) and forecast (bottom), of the northwestern hemisphere for December 1976.

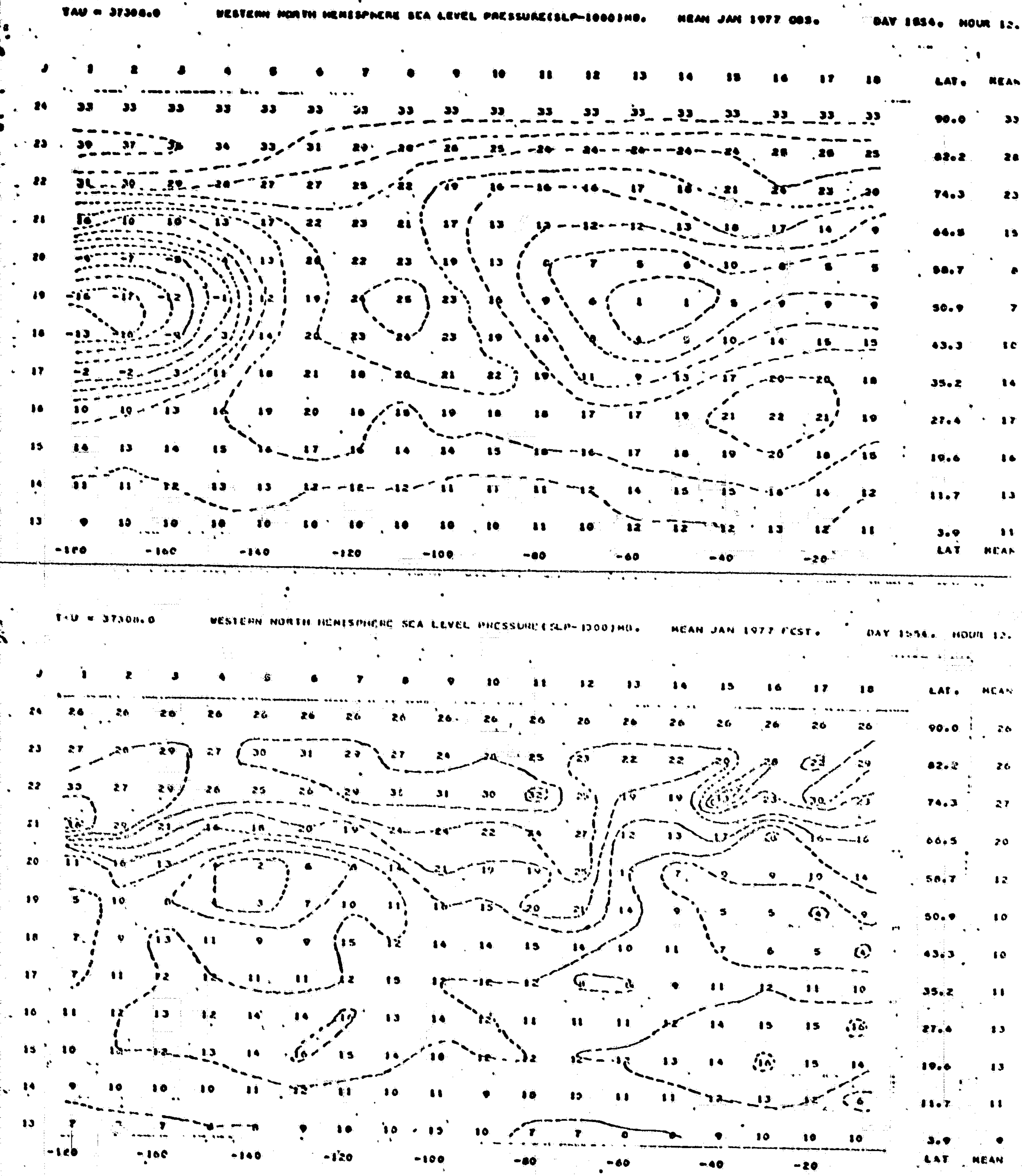


Figure 3(d) Sea-level pressure fields, observed (top) and forecast (bottom), of the northwestern hemisphere for January 1977.

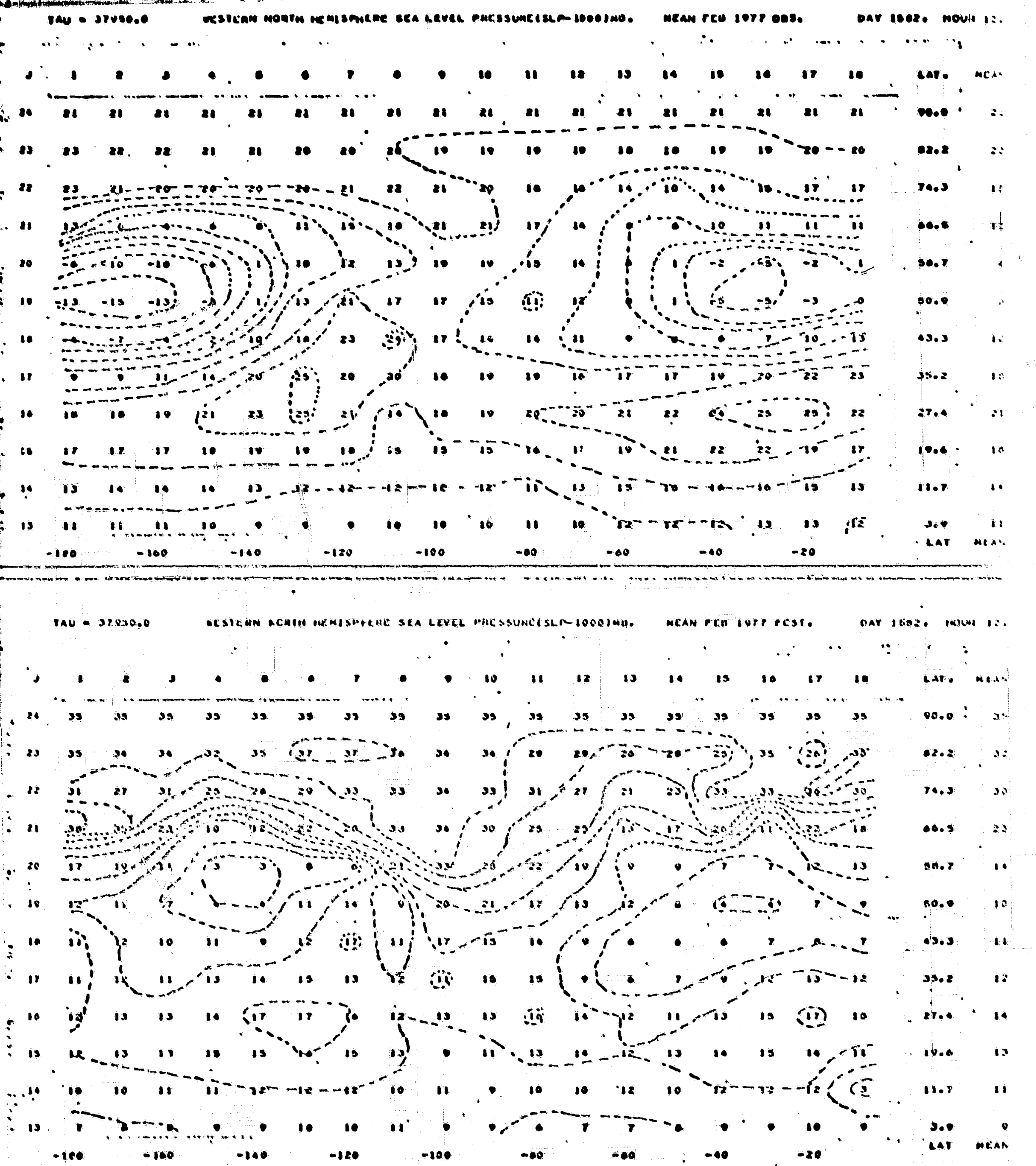


Figure 3(a) Sea-level pressure fields, observed (top) and forecast (bottom), of the northwestern hemisphere for February 1977.

The 850 mb isotherms in Figure 4 are drawn manually for an interval of 5° C. It is immediately apparent that the predicted temperatures are generally too low, especially in high latitudes. The cold Arctic may be due to the inadequacy of the eddy transport of sensible heat, a problem that is also present in the GISS model (Stone, et al., 1975). However, the present model simulation is too cold in the tropics as well, which suggests some other defect in the model. The dominant characteristic of the temperature field over the northwest quadrant from October through February was the large contrast between the high temperatures over the west coast of North America (e.g., 120° W) and the low temperatures in the east (e.g., 80° W), which became most pronounced in December and January and began to ameliorate in February. The model does simulate some aspects of this cold wave in the east, notably in November. However, the December and January simulations are less satisfactory, and in February, when the cold in the east had abated somewhat, the model predicted the most severe conditions.

To illustrate the thermal behavior of the model, Table 2 lists the observed and predicted deviations of 850 mb temperatures from the climatological normals at five selected grid points in the United States. The normal values are interpolated from Crutcher and Meserve

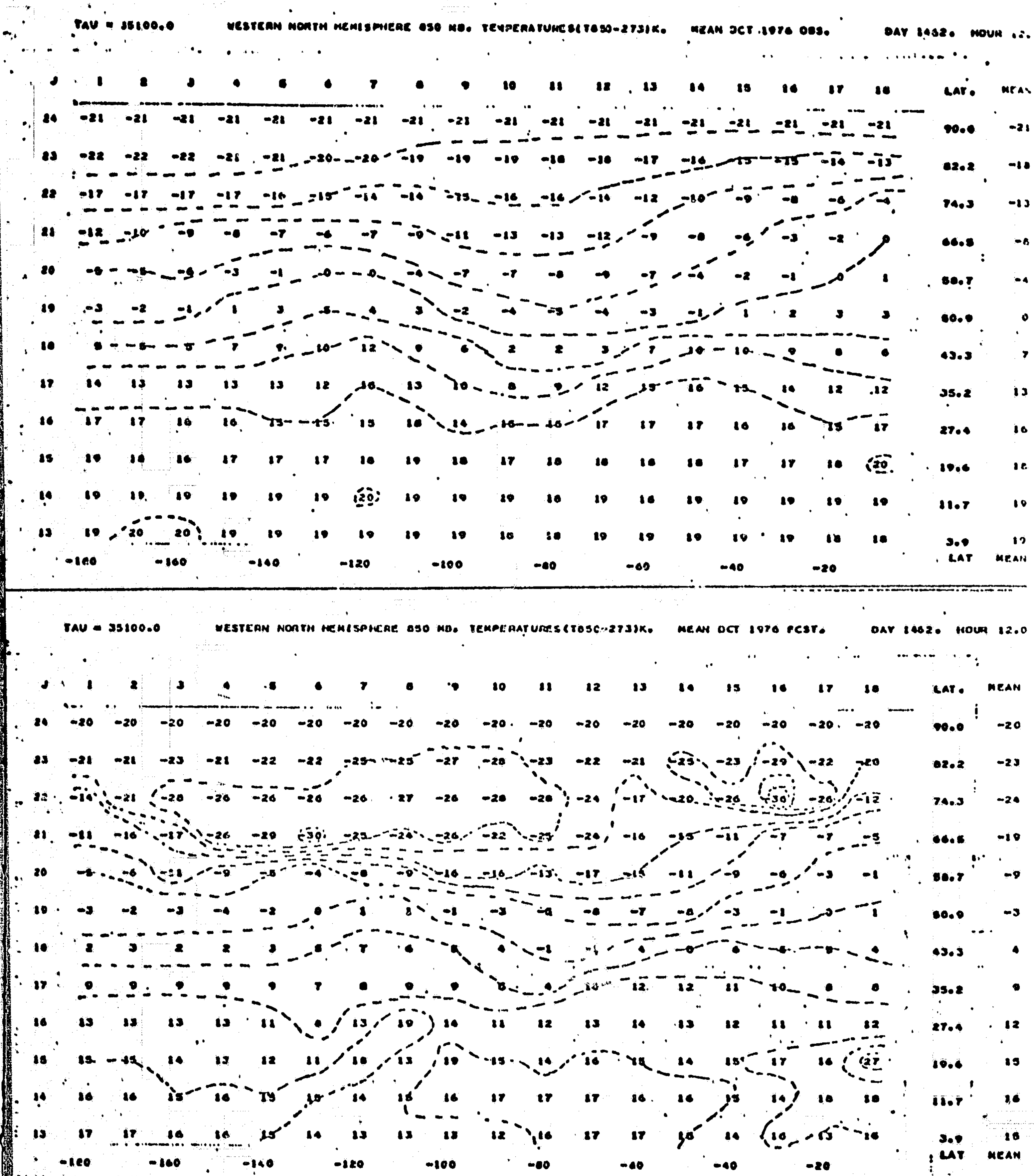


Figure 4(a) 850 mb. temperature fields, observed (top) and forecast (bottom), of the northwestern hemisphere for October 1976.

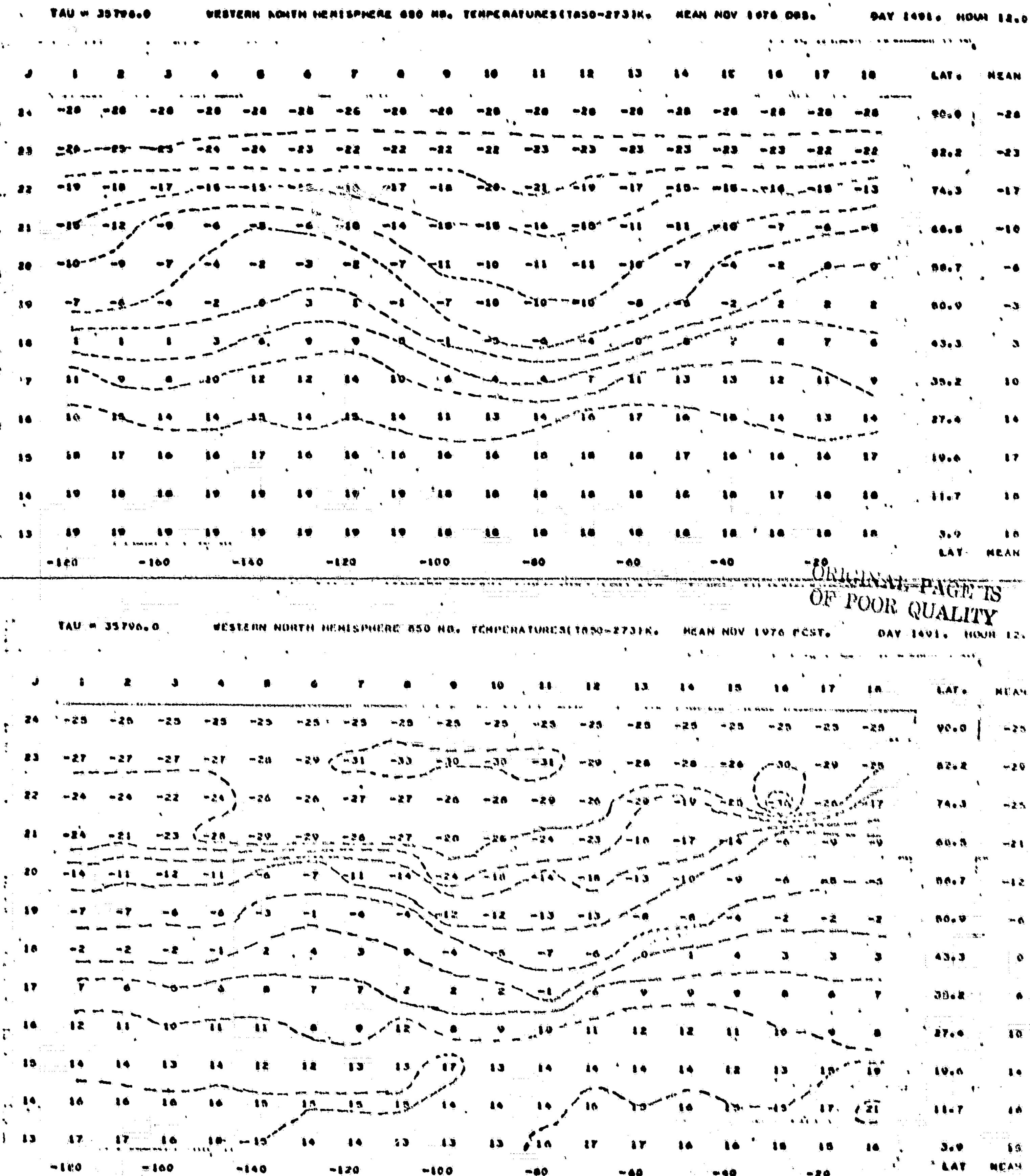


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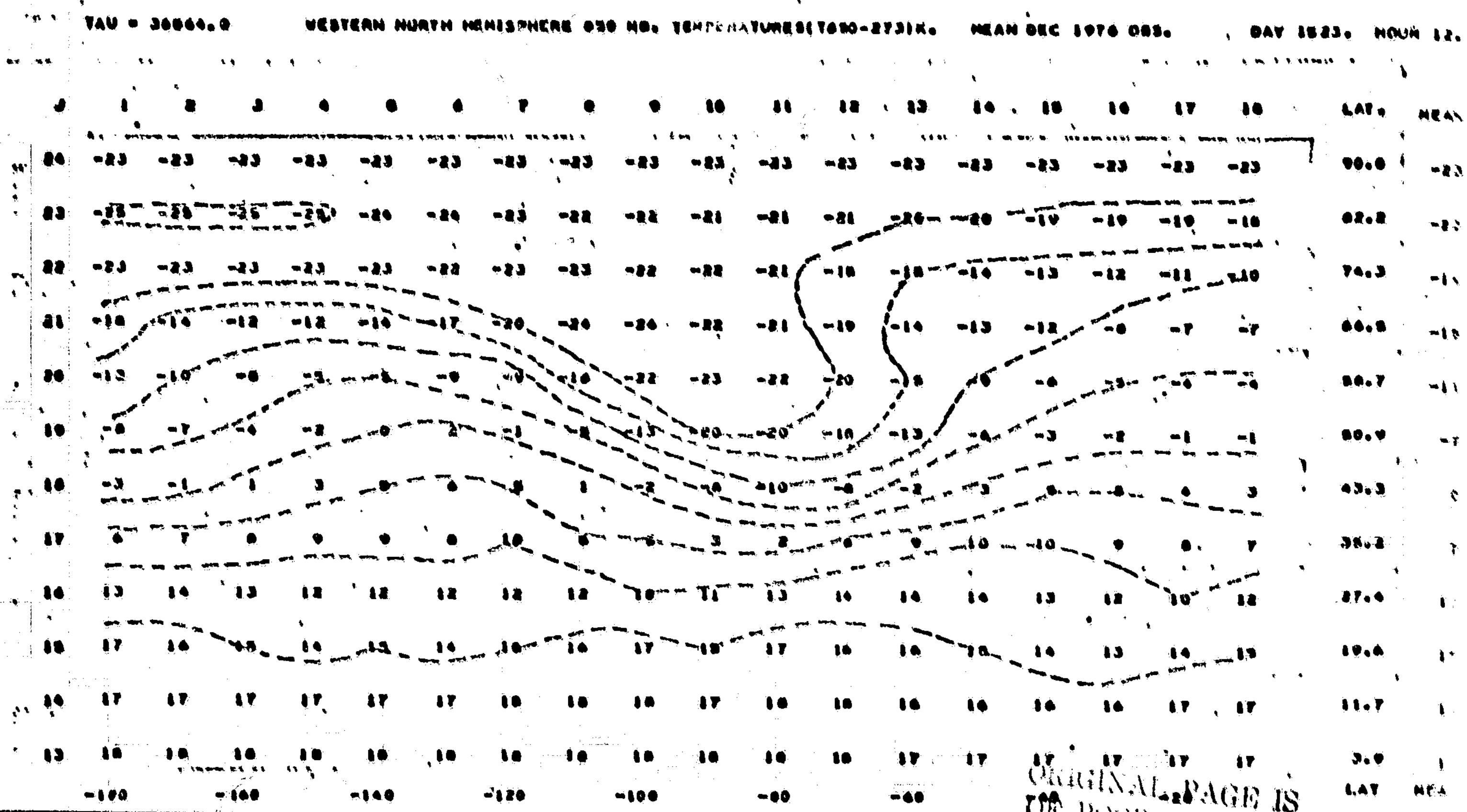
Figure 4(b) 850 mb. temperature fields, observed (top) and forecast (bottom), of the northwestern hemisphere for November 1976.



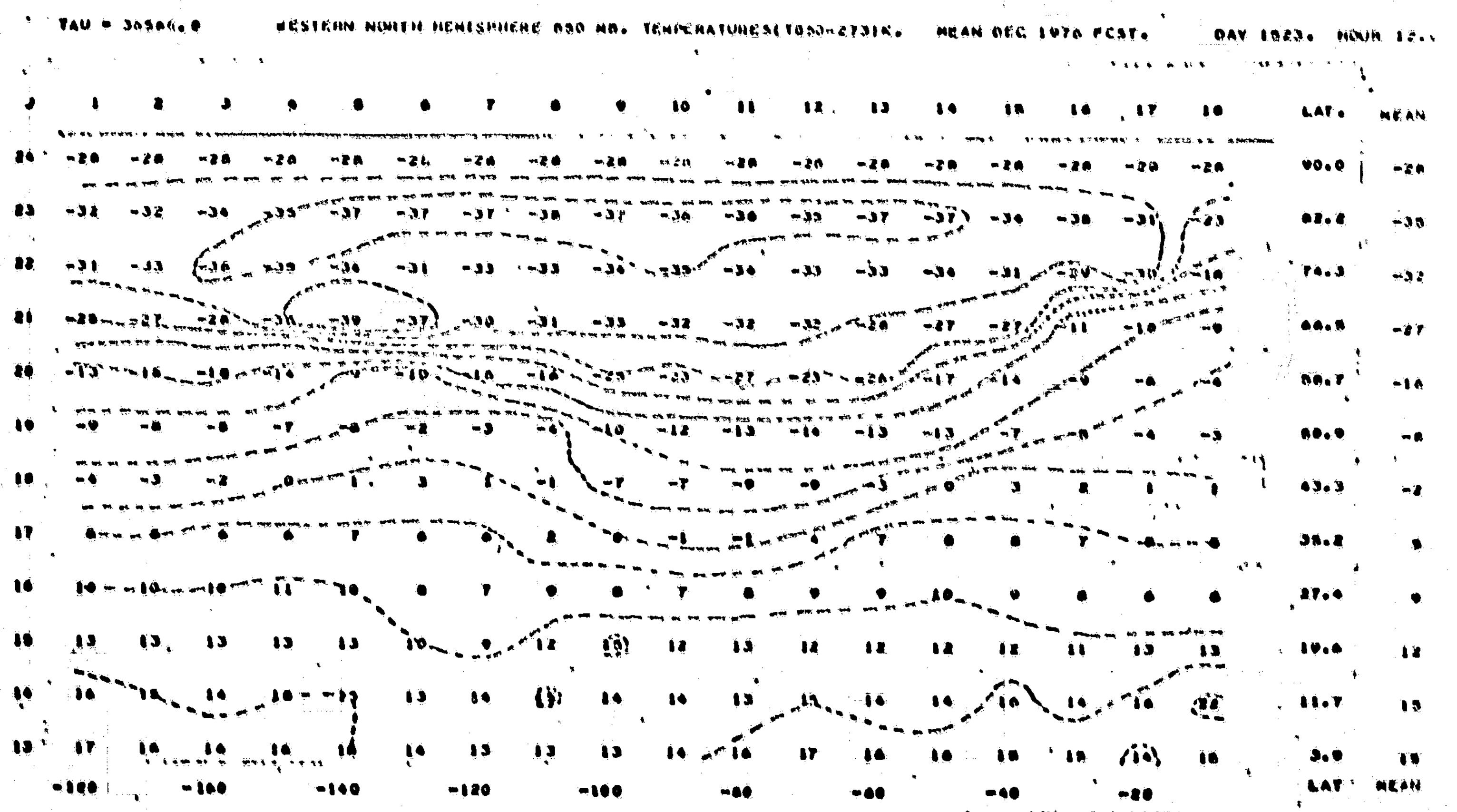
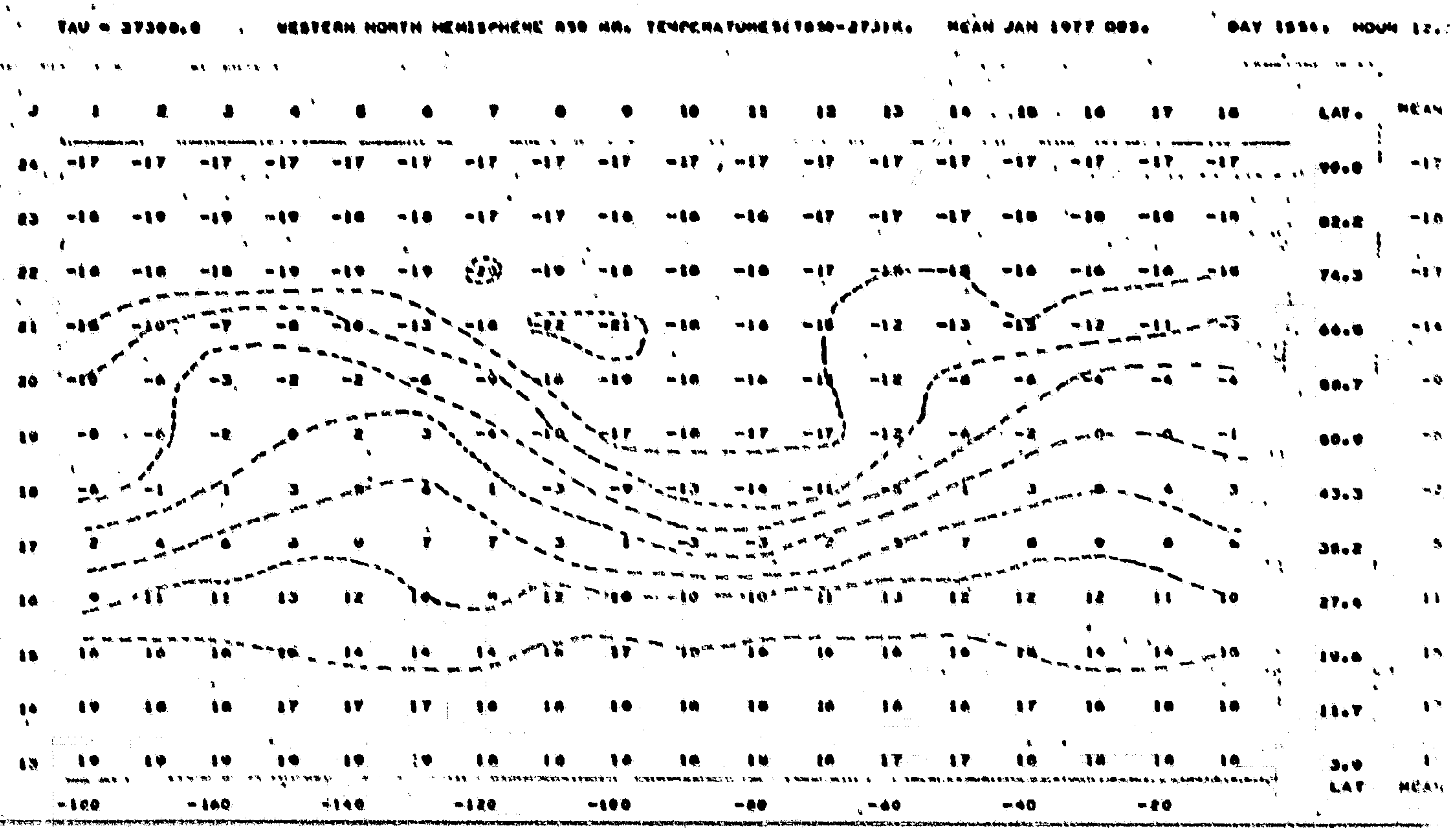


Figure 4(c) 850 mb. temperature fields, observed (top) and forecast (bottom), of the northwestern hemisphere for December 1976.



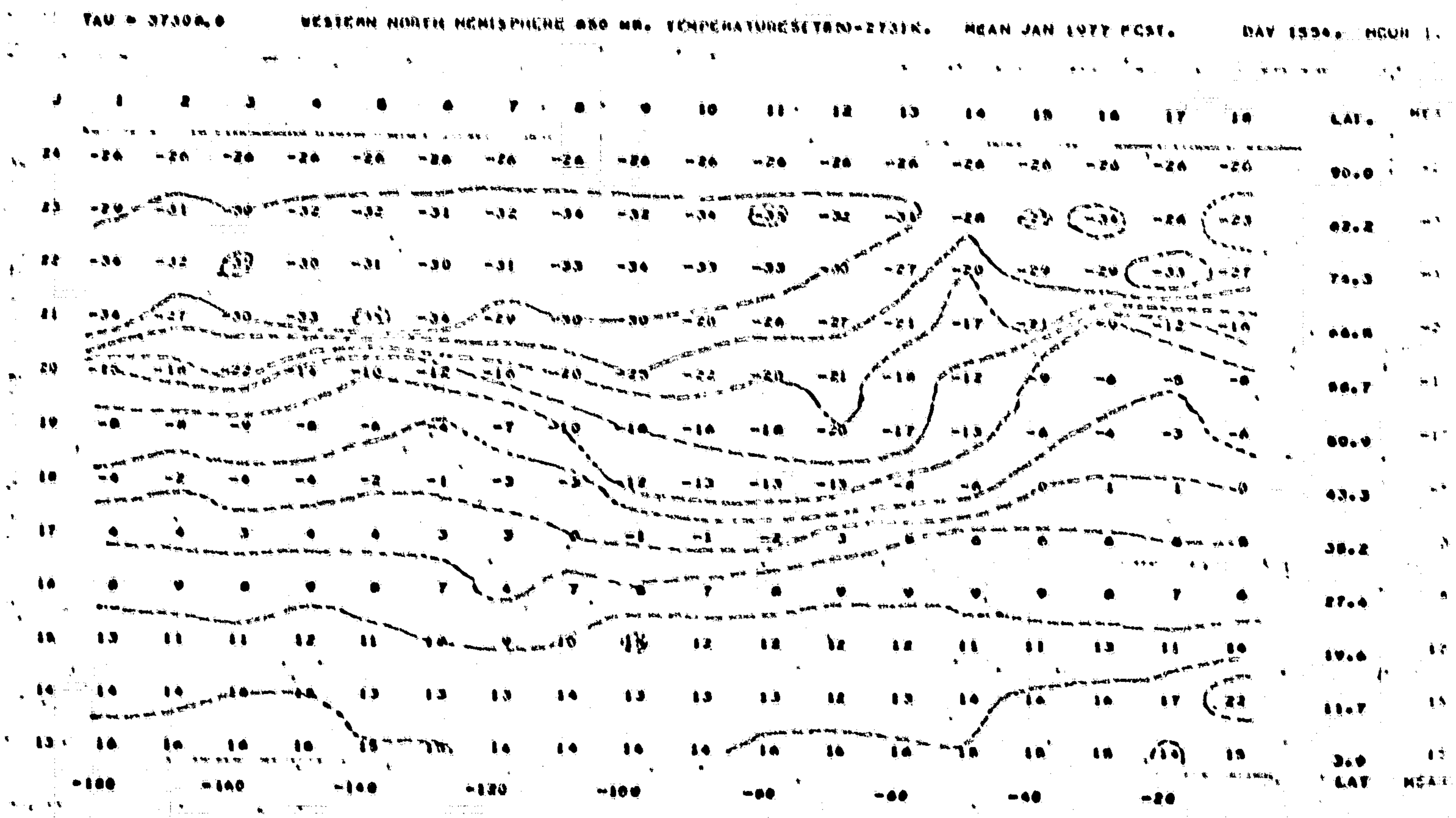
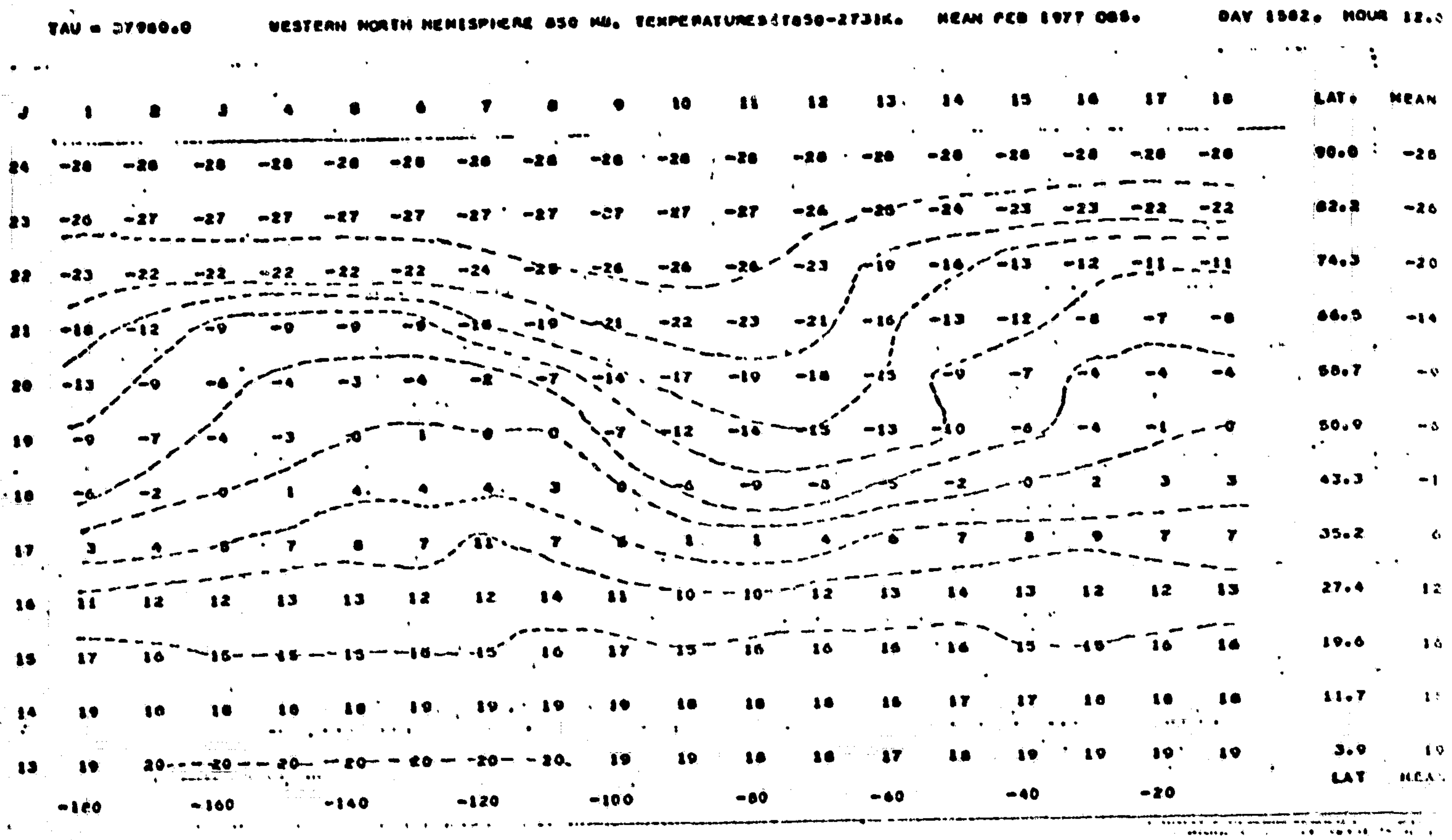


Figure 5(d) 850 mb. temperature fields, observed (top) and forecast (bottom), of the northwestern hemisphere for January 1977.



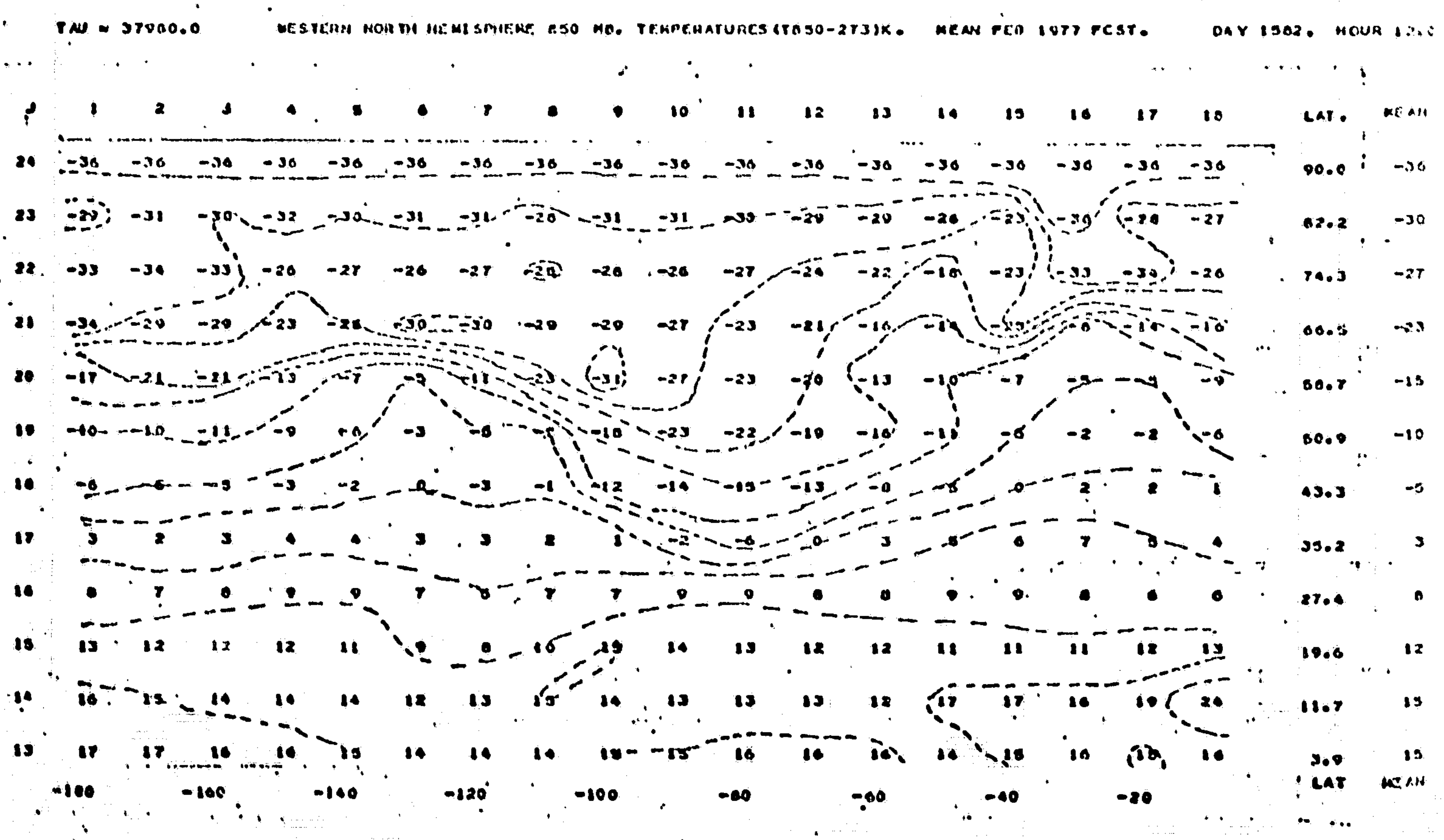


Figure 4(e) 850 mb. temperature fields, observed (top) and forecast (bottom), of the northwestern hemisphere for February 1977.

Table 2: Deviation from Normal of Observed and Forecast Temperatures at 850 mb for Selected Points (in ° K)

		Normal (N)	Observed (O)	Observed Deviation (O - N)	Forecast (F)	Forecast Deviation (F - N)
Oct.	Northeast	279	275	- 4	272	- 7
	Southeast	280	275	- 5	277	- 3
	Midwest	284	282	- 2	277	- 7
	N. Calif.	283	285	+ 2	280	- 3
	S. Calif.	287	288	+ 1	281	- 6
Nov.	Northeast	271	266	- 5	266	- 5
	Southeast	279	277	- 2	272	- 7
	Midwest	271	267	- 4	268	- 3
	N. Calif.	277	282	+ 5	277	0
	S. Calif.	281	287	+ 6	280	- 1
Dec.	Northeast	265	263	- 2	264	- 1
	Southeast	276	275	- 1	272	- 4
	Midwest	266	265	- 1	266	0
	N. Calif.	276	278	+ 2	274	- 2
	S. Calif.	282	283	+ 1	266	- 3
Jan.	Northeast	265	259	- 6	260	- 5
	Southeast	276	270	- 6	271	- 5
	Midwest	265	260	- 5	260	- 5
	N. Calif.	273	274	+ 1	270	- 3
	S. Calif.	280	281	+ 1	276	- 4
Feb.	Northeast	264	264	0	258	- 6
	Southeast	276	274	- 2	263	- 13
	Midwest	267	267	0	259	- 8
	N. Calif.	275	277	+ 2	270	- 5
	S. Calif.	280	284	+ 4	276	- 4

(1970). The grid points are located in the "Northeast" (43° N, 80° W), "Southeast" (35° N, 80° W), "Midwest" (43° N, 90° W), "Northern California" (43° N, 120° W), and "Southern California" (35° N, 120° W). While the model depicts large negative deviations from normal, it fails to simulate the phase opposition between the cold east and warm west, and in February it grossly exaggerates the cold anomaly in the east.

The observed and predicted 500 mb heights, together with manually-drawn 100 m contours, are displayed in Figure 5. The observed fields show the persistent stationary wave pattern (western ridge, eastern trough) mentioned earlier. The positions of the ridge and trough over North America are reasonably well-simulated in the prognostic maps. However, the amplitudes of the mean monthly waves, especially in November, December, and January, are not adequately reproduced, and the predicted flow in those months is much more zonal than the observed. The February 500 mb simulation is much closer to the observed field over North America. In all five months the predicted 500 mb heights are generally too low compared with the observed values, which is consistent with the fact that the troposphere is too cold in the model simulation.

TAU = 35100.0 WESTERN NORTH HEMISPHERE 500 MB. GEOPOT.HTS.((GP/10)-500)M. MEAN OCT 1976 OBS. DAY 1462. HOUR 12.

J	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	LAT.	MEAN
24	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	90.0	16
23	15	14	13	13	13	13	13	13	13	14	16	16	18	21	23	26	28	30	82.2	17
22	24	22	20	20	21	22	22	21	20	19	18	18	21	25	30	34	38	41	74.3	[illegible]
21	32	29	28	30	33	34	34	31	29	27	25	23	22	24	28	29	33	39	66.5	[illegible]
20	33	30	30	35	43	47	48	43	37	34	31	30	29	29	28	29	32	38	58.7	[illegible]
19	36	35	38	46	56	63	64	59	50	45	42	41	43	45	47	47	45	45	50.9	[illegible]
18	60	58	59	65	71	76	76	71	65	60	58	61	66	72	74	72	66	61	43.3	[illegible]
17	82	80	78	78	79	80	80	76	73	73	73	78	82	85	87	86	81	75	35.2	[illegible]
16	89	87	85	84	83	83	83	82	82	83	84	86	87	87	87	87	85	84	27.4	[illegible]
15	89	88	87	87	86	86	86	87	87	87	87	87	87	88	88	87	88	88	19.6	[illegible]
14	89	88	88	88	87	87	87	87	87	87	86	87	87	89	89	89	89	89	11.7	[illegible]
13	88	88	88	88	88	87	87	87	87	87	87	87	87	88	88	88	88	88	3.9	[illegible]
																			LAT	MEAN

-180 -160 -140 -120 -100 -80 -60 -40 -20

TAU = 35100.0 WESTERN NORTH HEMISPHERE 500 MB. GEOPOT.HTS.((GP/10)-500)M. MEAN OCT 1976 FCST. DAY 1462. HOUR 12.

J	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	LAT.	MEAN
24	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	90.0	12
23	19	15	14	12	11	11	6	5	5	5	5	8	10	11	14	12	13	16	82.2	11
22	28	23	16	12	10	10	9	8	6	5	4	5	11	16	20	22	22	25	74.3	14
21	32	28	19	14	14	14	16	15	12	10	6	7	11	16	22	25	30	33	66.5	18
20	36	36	29	23	27	32	31	31	28	23	21	19	19	22	25	28	31	35	58.7	28
19	41	44	42	37	38	46	51	49	47	43	39	38	39	40	41	41	40	41	50.9	42
18	56	57	58	55	55	57	63	62	57	56	52	51	57	61	61	58	55	54	43.3	57
17	69	69	68	68	68	64	65	68	66	64	60	64	69	72	72	69	66	64	35.2	67
16	76	75	75	75	74	72	72	75	75	72	71	72	75	75	75	72	71	71	27.4	74
15	78	78	78	76	77	77	78	80	79	79	78	78	78	78	78	78	80	81	19.6	78
14	80	79	79	79	79	79	79	79	79	79	79	79	79	79	80	79	80	81	11.7	79
13	80	80	79	80	79	80	79	79	79	79	79	78	79	79	79	80	80	80	3.9	79
																			LAT	MEAN

-180 -160 -140 -120 -100 -80 -60 -40 -20

Figure 5(a) 500 mb. geopotential height fields, observed (top) and forecast (bottom), of the northwestern hemisphere for October 1976.

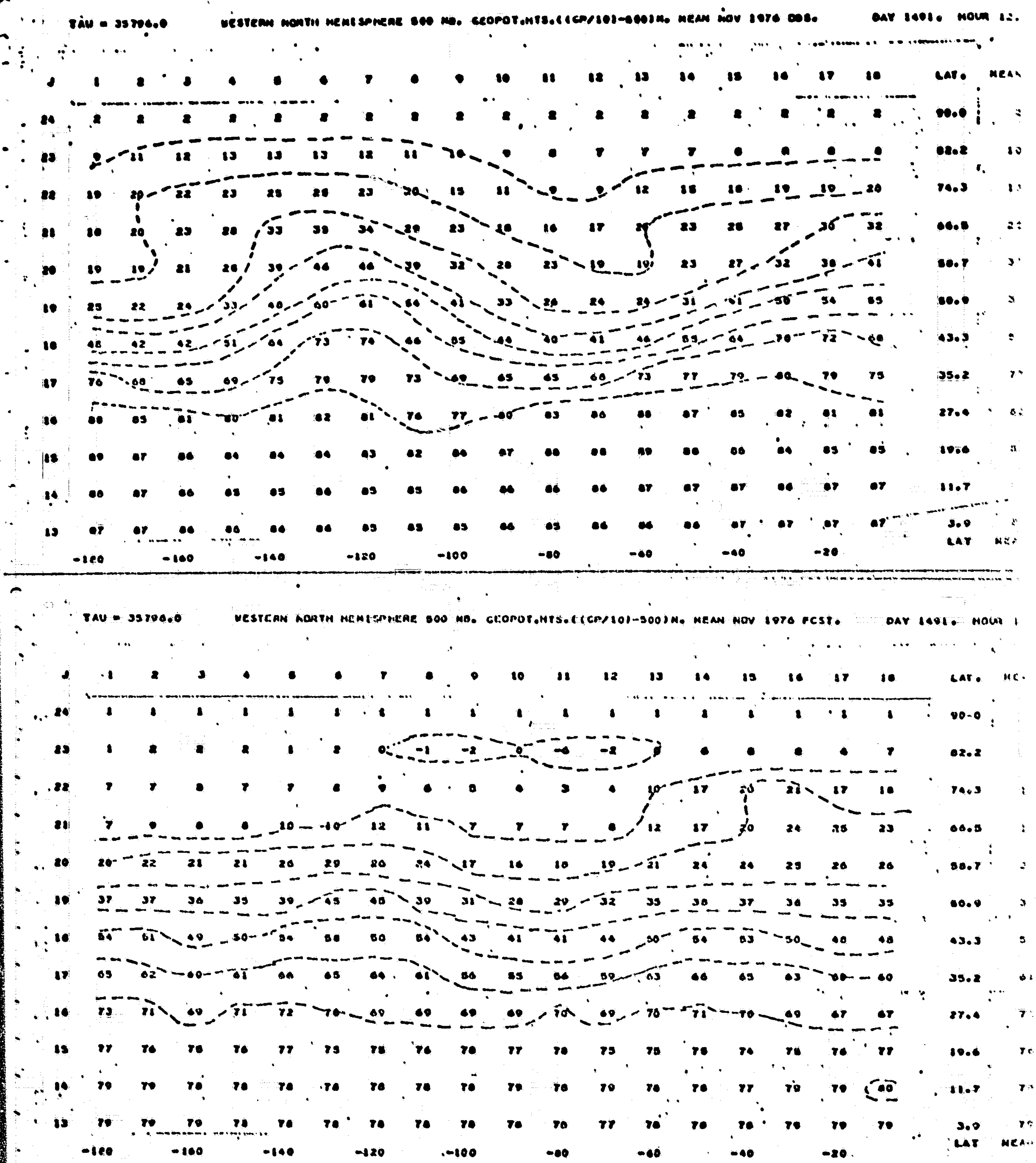
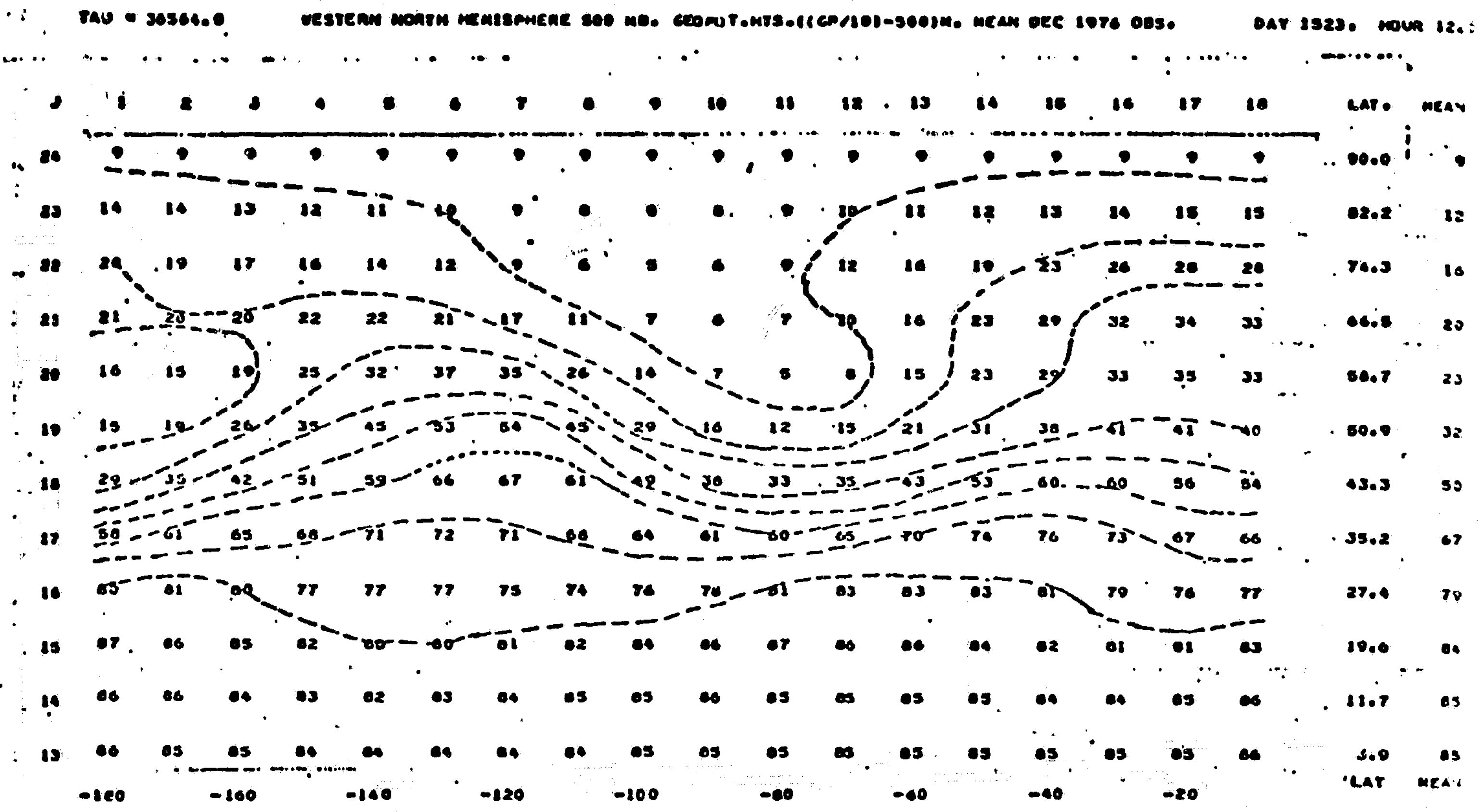


Figure 5(b) 500 mb. geopotential height fields, observed (top) and forecast (bottom), of the northwestern hemisphere for November 1976.



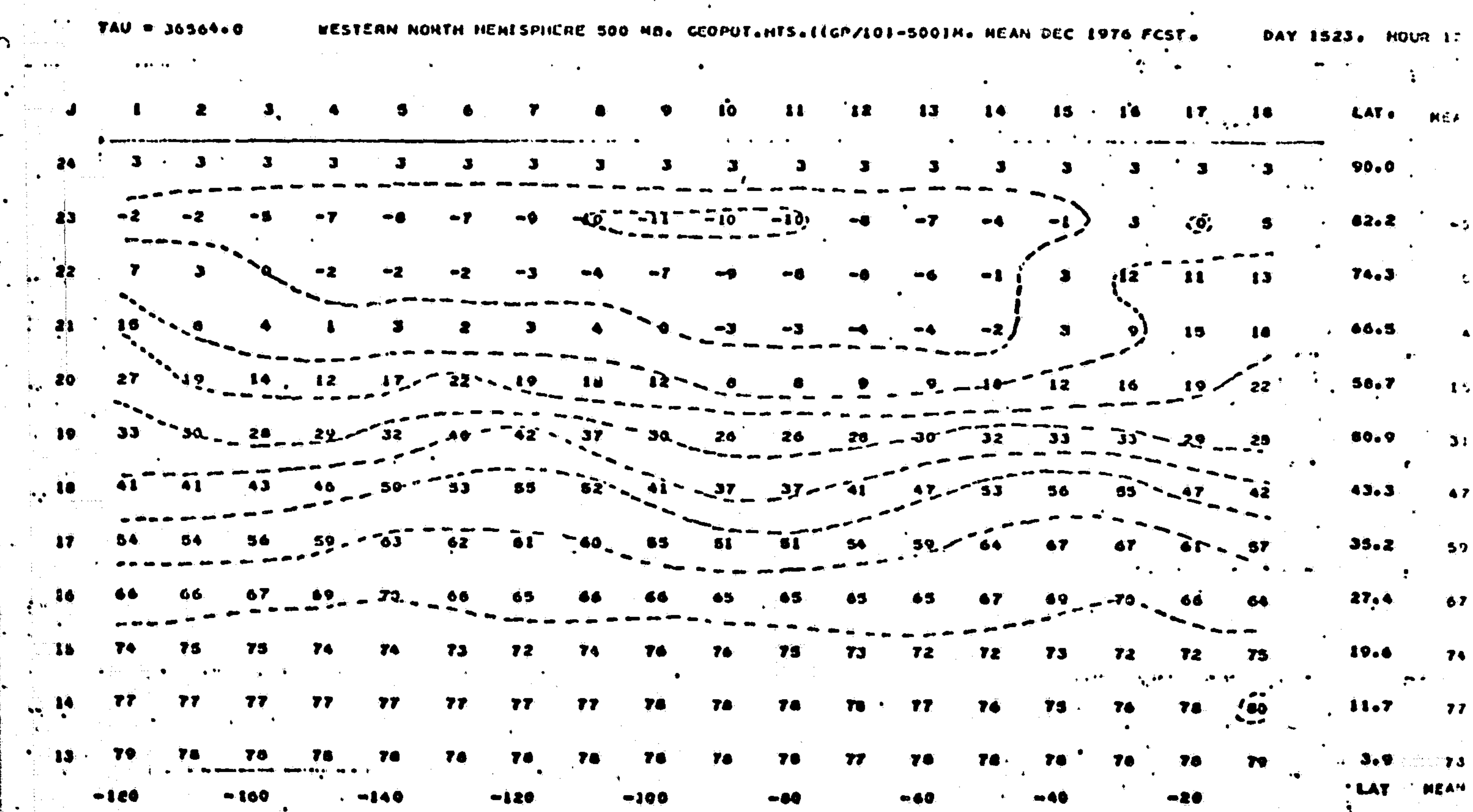
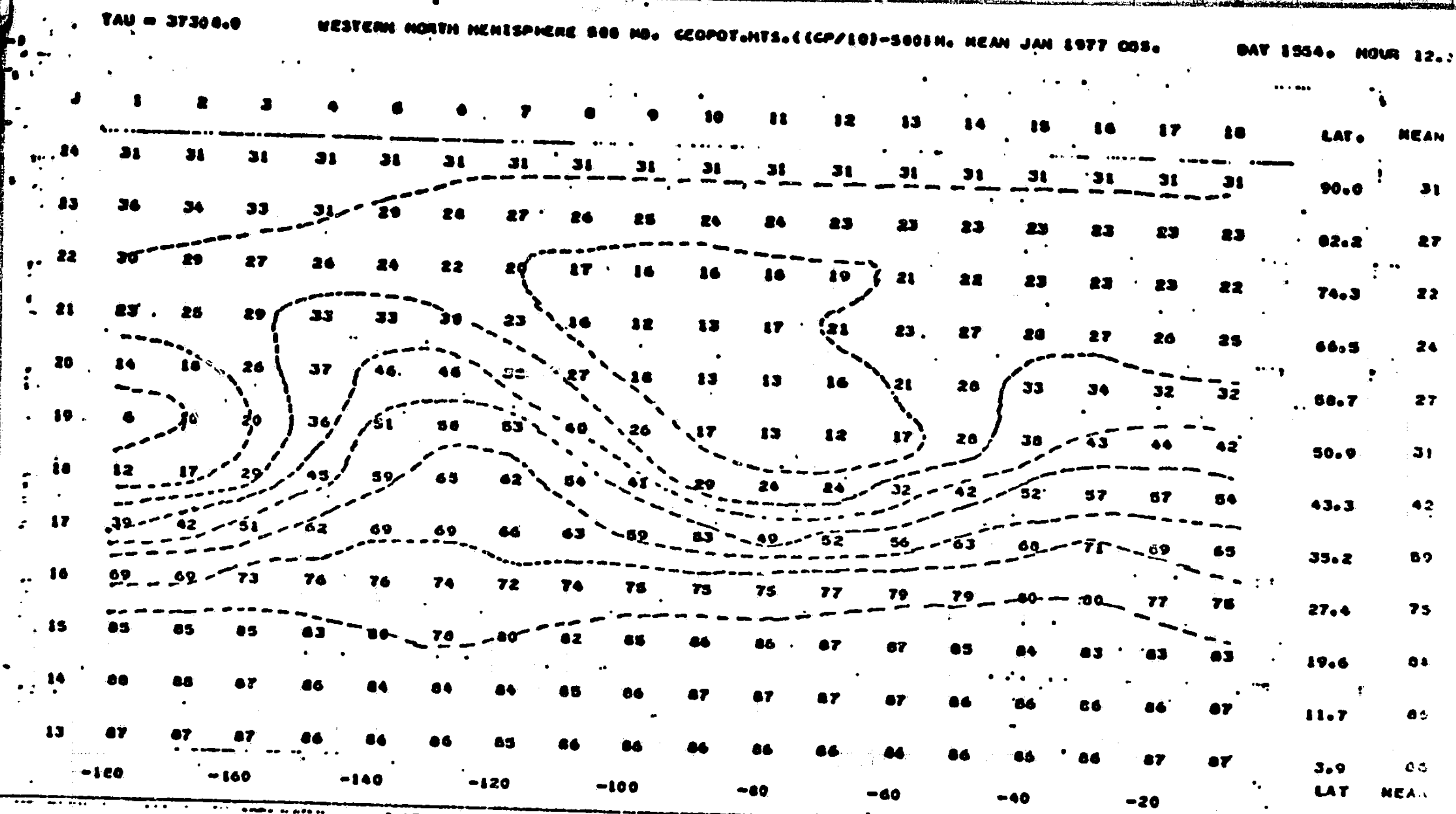


Figure 5(c) 500 mb. geopotential height fields, observed (top) and forecast (bottom), of the northwestern hemisphere for December 1976.



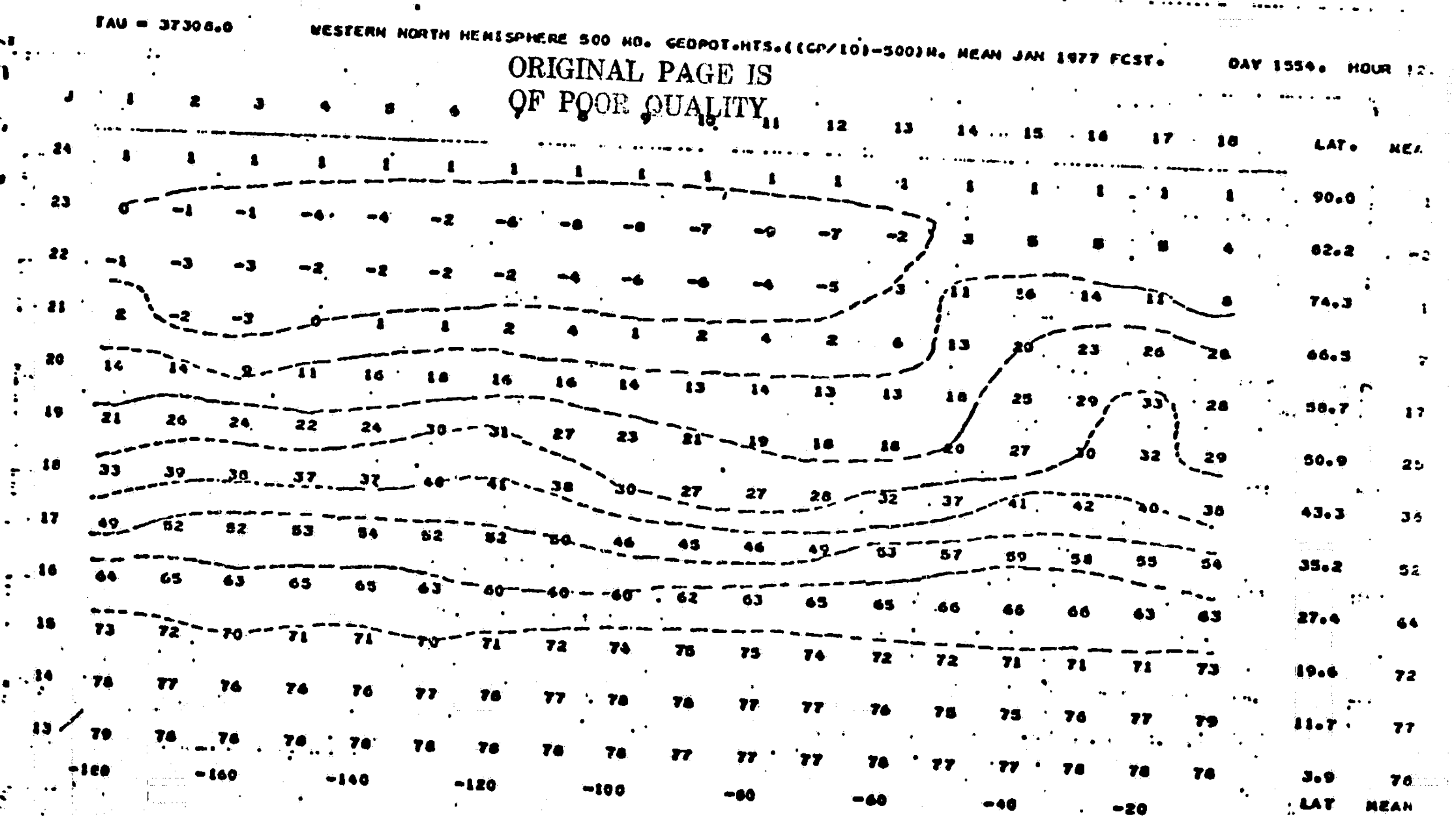
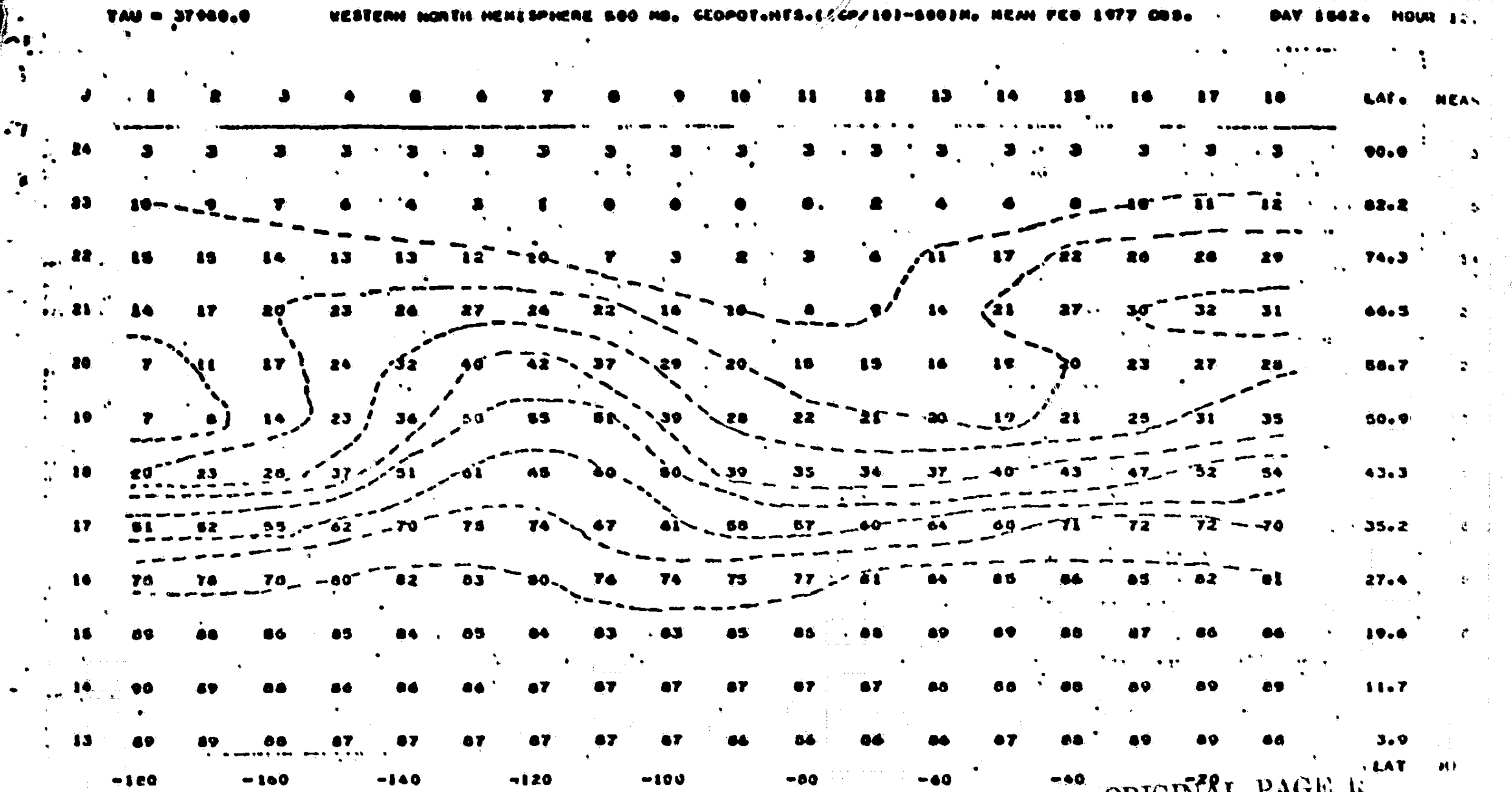


Figure 5(d) 500 mb. geopotential height fields, observed (top) and forecast (bottom), of the northwestern hemisphere for January 1977.



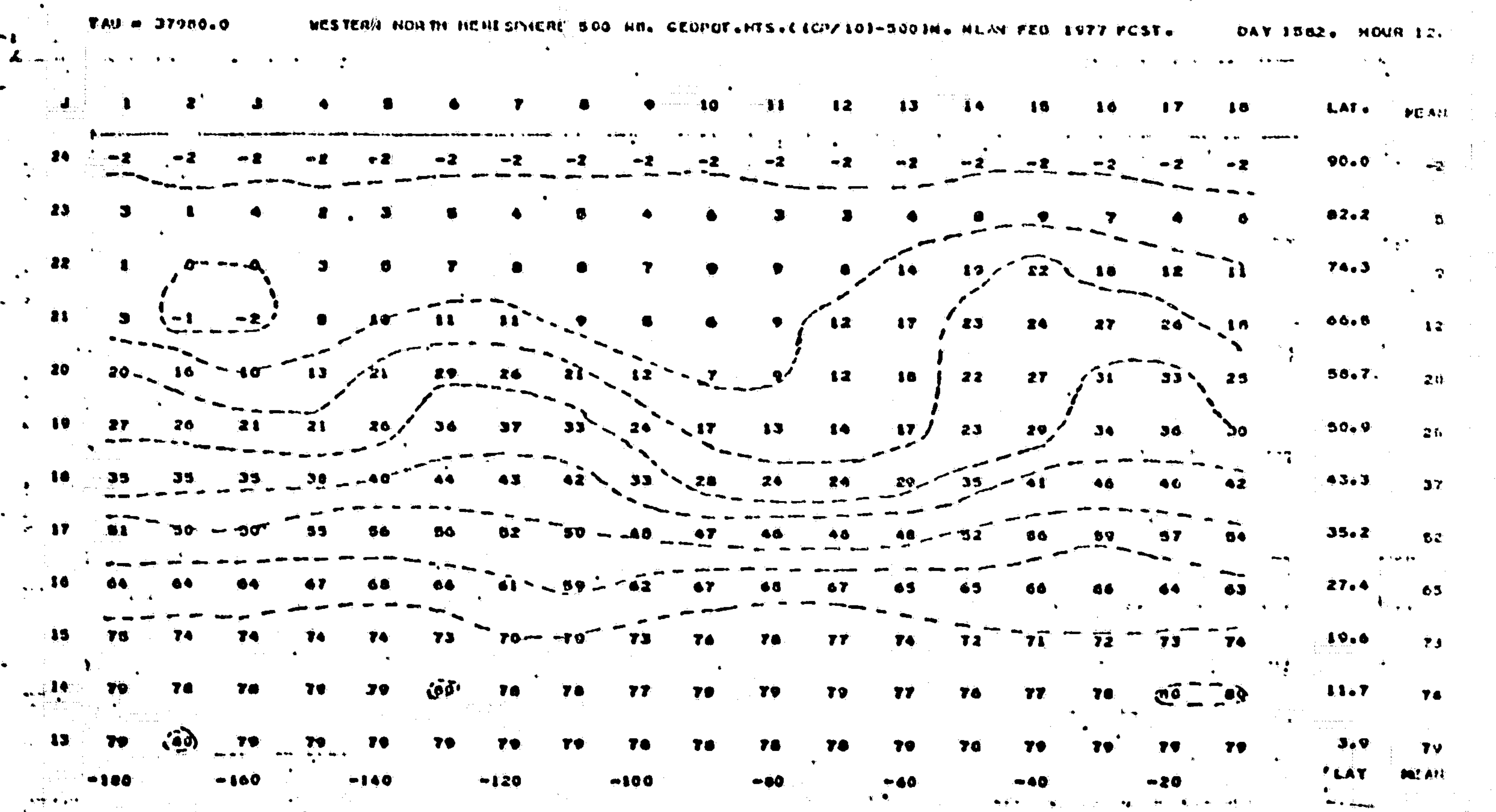


Figure 5(c) 500 mb. geopotential height fields, observed (top) and forecast (bottom), of the northwestern hemisphere for February 1977.

Error Statistics

The statistical analysis is based on the computation of root-mean-square (rms) errors and S1 skill scores for each month, applied to the three variables: sea-level pressure, 850 mb temperature and 500 mb geopotential heights. The S1 skill score (Teweles and Wobus, 1954) is a conventional measure of the difference between the predicted and observed horizontal gradients. It is dimensionless, and has a possible range from zero, for a perfect simulation, to 200, which is the maximum and represents no correspondence at all between the fields. It is generally agreed (based on experience at NMC) that a score of 20 indicates practically a perfect forecast and a score of 70 or greater represents a worthless forecast. The algebraic mean differences between forecasts and observations (forecast - observed) are also presented in the table of statistics below.

Error statistics are shown for seven regions: (1) United States (27° N to 51° N and 130° W to 70° W); (2) East Pacific and United States (27° N to 51° N and 180° W to 70° W); (3) North America (27° N to 74° N and 130° W to 70° W); (4) Europe (35° N to 74° N and 10° W to 40° E); (5) Tropics (20° N to 20° S over all longitudes); (6) Northern hemisphere (4° N to 82° N over all longitudes); (7) Globe (82° S to 82° N over all longitudes).

Table 3, which presents the algebraic mean errors (forecast - observed) of the simulations, shows quantitatively the bias of the model. Sea-level pressures are generally underpredicted, although not universally. (As shown earlier, in the Icelandic and Aleutian regions the predicted pressures are generally too high. However, in the Arctic, over the continents, and in the oceanic subtropical anticyclones, the model underpredicts the pressures.) Over the northern hemisphere the average bias for the five months is - 2.1 mb. The 850 mb data indicate that the model temperatures are too low everywhere, including the tropics. The cold bias over the northern hemisphere is - 3.5° C for the five-month period. At the 500 mb level, the predicted geopotential heights are consistently too low over all regions, with an average bias of - 93 m for the five-month period over the northern hemisphere. This result is, of course, hydrostatically consistent with the 850 mb temperature bias.

The rms errors and S1 skill scores for the five monthly mean simulations are shown in Table 4. There appear to be no systematic differences in the errors from month to month and no seasonal trends. With regard to regional differences, the rms errors are smallest in the tropics. Over the northern hemisphere, the average rms errors for the five-month period are 6.7 mb, 5.4° C

Table 3: Algebraic Mean Difference (Bias) between Monthly Mean Forecast and Observed Values (Forecast - Observed) for Winter 1976-1977

		Algebraic Mean Difference					
		Oct.	Nov.	Dec.	Jan.	Feb.	Avg.
SLP (mb)	United States	- 2.1	- 1.2	- 1.7	- 5.2	- 4.3	- 2.9
	E. Pacific & U.S.	- 1.7	+ 0.7	- 0.4	- 0.2	- 0.6	- 0.4
	North America	+ 0.7	+ 1.4	+ 0.9	- 2.6	- 0.7	0.0
	Europe	- 2.6	- 5.8	- 3.1	- 5.8	- 2.8	- 4.0
	Tropics	- 2.7	- 3.0	- 1.8	- 2.1	- 3.3	- 2.6
	Northern Hemis.	- 1.4	- 1.7	- 1.3	- 2.2	- 1.5	- 2.1
	Globe	+ 1.2	- 0.3	+ 1.2	+ 0.2	+ 0.1	+ 0.5
T 850 (° C)	United States	- 2.9	- 4.0	- 2.0	- 2.2	- 5.6	- 3.3
	E. Pacific & U.S.	- 3.1	- 3.7	- 2.2	- 2.6	- 4.7	- 3.3
	North America	- 5.0	- 5.5	- 3.6	- 4.2	- 5.9	- 4.8
	Europe	- 4.6	- 4.0	- 3.1	- 4.2	- 5.9	- 4.4
	Tropics	- 3.0	- 2.5	- 2.4	- 2.9	- 2.9	- 2.7
	Northern Hemis.	- 3.6	- 3.5	- 3.4	- 3.5	- 3.7	- 3.5
	Globe	- 4.5	- 3.9	- 4.0	- 4.2	- 4.4	- 4.2
G 500 (M)	United States	- 100	- 97	- 70	- 102	- 143	- 102
	E. Pacific & U.S.	- 91	- 72	- 60	- 66	- 96	- 77
	North America	- 111	- 106	- 77	- 115	- 123	- 106
	Europe	- 136	- 147	- 107	- 149	- 156	- 139
	Tropics	- 84	- 80	- 77	- 85	- 87	- 83
	Northern Hemis.	- 94	- 91	- 86	- 100	- 93	- 93
	Globe	- 86	- 90	- 80	- 91	- 89	- 87

Table 4: Root-mean-square (rms) Errors and S1 Skill Scores of Monthly Mean Simulations for Winter of 1976-1977

		rms Errors					S1 Scores				
		Oct.	Nov.	Dec.	Jan.	Feb.	Oct.	Nov.	Dec.	Jan.	Feb.
SLP (mb)	United States	3.5	5.1	4.5	4.3	6.0	95	120	115	156	105
	E. Pacific & U.S.	4.3	7.2	6.8	10.3	8.7	112	140	133	156	139
	North America	6.4	7.1	7.4	8.9	7.5	106	114	115	138	91
	Europe	5.5	8.1	4.4	5.1	7.3	85	125	85	90	108
	Tropics	3.3	3.7	2.8	2.9	4.1	72	69	72	68	70
	Northern Hemis.	5.3	7.2	6.1	7.2	7.8	95	102	90	89	87
	Globe	8.5	6.7	7.0	7.4	8.2	88	85	89	84	83
T 850 (° C)	United States	3.7	4.4	3.8	3.3	6.1	48	37	38	36	44
	E. Pacific & U.S.	3.7	4.0	3.4	3.8	5.3	41	30	34	42	41
	North America	6.8	6.7	5.9	6.2	7.1	65	50	58	53	61
	Europe	5.5	5.1	4.0	5.7	6.6	61	67	76	93	65
	Tropics	3.6	3.2	2.9	3.4	3.6	75	86	83	98	97
	Northern Hemis.	5.1	5.2	5.5	5.9	5.4	66	65	67	67	62
	Globe	6.8	6.3	6.2	6.5	6.6	61	61	62	64	61
G 500 (M)	United States	109	115	105	133	149	39	45	38	50	30
	E. Pacific & U.S.	106	108	102	65	136	45	51	43	65	43
	North America	119	124	109	146	139	41	49	49	65	42
	Europe	157	160	115	160	162	65	76	54	71	46
	Tropics	85	82	78	86	90	53	71	83	72	102
	Northern Hemis.	104	114	112	131	119	52	71	67	67	62
	Globe	102	107	99	114	109	45	50	52	54	49

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and 116 m for sea-level pressure, 850 mb temperature and 500 mb height, respectively. These may be compared with the corresponding average rms errors for the four months (January 1973, 1974, 1975, and February 1976) for which GISS model simulations were performed (Spar, 1977 b). The averages of the GISS-model rms errors were 8.2 mb, 4.3° C and 74 m, respectively. In terms of the sea-level pressure field, the coarse-mesh model simulations are actually slightly better than those of the finer-mesh GISS model, although neither set is satisfactory. With regard to 850 mb temperatures and 500 mb heights, however, the coarse-mesh model produces a less satisfactory simulation than does the GISS model.

The S1 scores shown in Table 4 indicate that the Hansen model, like the GISS model, exhibits no skill in simulating the sea-level pressure field. (Over the northern hemisphere, the five-month average S1 score for sea-level pressure is 93, a "worthless" forecast.) At the 850 mb level, the S1 scores for the simulations of the temperature pattern are much better, especially over the United States. However, over the northern hemisphere they are disappointingly high, with a five-month average value of 64, compared with the four-month GISS-model average of 46. This suggests only marginal skill for the Hansen model at the 500 mb level compared with the more satisfactory performance of the GISS model.

Summary and Conclusions

The five prediction experiments conducted in this study appear to indicate that, at the present stage of its development, the coarse-mesh model does not yet produce a satisfactory simulation of the monthly mean atmosphere.

The mean zonal kinetic and available potential energies are consistently overpredicted by the model, while the eddy kinetic and eddy available potential energies are underpredicted.

The meridional and vertical wind profiles of the model agree with the observed monthly mean profiles only in broad qualitative structure, but not in quantitative detail.

There is a serious negative bias in the predicted 850 mb temperatures and 500 mb geopotential heights.

The model exhibits no skill in simulating the monthly mean sea-level pressure field, and only marginal skill in reproducing the 850 mb temperatures and 500 mb heights over the northern hemisphere. Over North America the performance is somewhat better, but it still fails to simulate adequately the evolution of the anomalous cold winter of 1976-1977.

The coarse-mesh model appears to be somewhat less satisfactory than the finer-mesh GISS model in simulating the 850 mb temperature and 500 mb height fields.

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